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# BULLETIN

OF THE

## AMERICAN PHYSICAL SOCIETY

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INCLUDING THE

PROGRAMME OF THE

## 1959 ANNUAL MEETING

AT

NEW YORK, NEW YORK

January 28–31, 1959

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# BULLETIN

of the

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January 28, 1959 Series II, Vol. 4, No. 1, Part 1

# BULLETIN

OF THE

# AMERICAN PHYSICAL SOCIETY

1959 Annual Meeting at New York, January 28–31, 1959

THE **1959 Annual Meeting of the American Physical Society** will be held at New York on Wednesday, Thursday, Friday, and Saturday, **January 28 through 31,** 1959. The American Association of Physics Teachers (hereinafter to be denoted by AAPT) will share in the Ceremonial Session and in the banquet. The play will be wholly new, but the staging will be the same as that of last year. The headquarters hotel will be the New Yorker, as it has been for several years, and most of the sessions will be held in its various halls; but we shall also be using a hall in the Governor Clinton Hotel opposite the southeast corner of Penn Station, and the Ceremonial Session will have Manhattan Center for its theater in the literal sense of this term. The banquet will as last year be held in the Terrace Room of the New Yorker on Friday evening at 7:00 P.M.

Much of the above is taken verbatim from the *Bulletin* of the 1958 Annual Meeting, and in conformance with its precedent we again can announce a slight decline in the number of ten-minute papers —not enough to be of significance, but a rise could have impaired the opportunities for invited papers, and we should indeed be hampered if we were still on the three-day schedule of earlier years. Some of the sessions of contributed papers are too long as it is. But for the unstinted aid of the American Institute of Physics, we could scarcely hope to hold so great a convention as this will be if it matches in attendance those of the three past years.

To repeat: the **official hotel is the New Yorker,** which is at Eighth Avenue and 34th Street, a block north of the northwest corner of Penn Station. The Eighth Avenue IND subway stop is at the New Yorker, the Seventh Avenue (West Side IRT) subway stop is at the east side of Penn Station. Manhattan Center is just to the west of the New Yorker; the location of the Governor Clinton Hotel has been described above. Those who have not yet made their room reservations should attend to this at once, and the form letter on page 73 of this Bulletin is inserted for them to use.

The **registration desk** will be located in the North Ballroom Foyer on the mezzanine floor of the New Yorker (same place as last year and the year before). Banquet tickets will be sold there, up to 6 P.M. on Thursday. Post-deadline papers, if any, will be announced on a blackboard near the desk. There will be a special blackboard for notice of messages and of changes, should there be any, in arrangements. **On Tuesday, from 5 to 10 P.M., there will be a desk for pre-registration in the lobby of the hotel.**

The **registration fee** will be two dollars, payable at the desk. We do not repeat the arguments for this fee, already several times printed. To those acquainted with the fees of other societies, it is more likely to appear absurdly small than unreasonably large. We insist on registration, and we do not accept messages to be posted for anyone who has not registered.

The **banquet of the American Physical Society and the AAPT** will be held on Friday evening in the Terrace Room of the New Yorker. The after-dinner programme will involve two of the most active fields of physics: H. L. Dryden will speak on "Physicists in the National Space Programme," and there will be a showing of the AEC film "Research into Controlled Fusion." It will not be considered cricket for anyone to try to hear the speech or see the film without buying a dinner ticket. Since the banquet is being held on the third day of the meeting, we are not asking for advance reservations. You must, however, buy your tickets not later than 6 P.M. on *Thursday* at the registration desk: the hotel sets places for only 5% more than the number of tickets sold by that time. Your tickets will be held for you if you pay in advance (by check made out to American Physical Society and mailed to Mrs. Emily Wolf, 335 East 45th Street, New York 17, New York). The price will be $5.50.

The **Joint Ceremonial Session** of the two Societies will be held in Manhattan Center on Thursday afternoon, beginning at 2:00 P.M. Our retiring President, J. W. Beams, will deliver his address entitled "High-Speed Rotation." The Oersted Medal of the AAPT will be conferred upon Paul Kirkpatrick, who will respond with a speech en-

titled "On Colleagues and Clients." The seventeenth Richtmyer Memorial Lecture of the AAPT, entitled "Masers and their Applications," will be given by Charles H. Townes.

The **Oliver E. Buckley Solid-State Physics Prize** for 1959 will be awarded at the banquet to Conyers Herring.

**Invited papers on the general programme** are by Elizabeth J. Allin, C. A. Barnes, R. H. Bube, J. H. Burgess, R. L. Cool, M. F. Crawford, K. M. Crowe, P. A. M. Dirac, J. W. M. DuMond, Joan Freeman, M. L. Goldberger, H. E. Gove, W. A. Hardy, G. W. Ludwig, Hermann Mark, R. E. Marshak, E. B. Paul, Frank Pipkin, R. J. Plano, A. M. Portis, Henry Primakoff, Louis Rosen, Gertrud Scharff-Goldhaber, Kenneth Smith, M. Tinkham, A. V. Tollestrup, R. J. Van de Graaff, J. van Kranendonk, and R. L. Walker. There will be a **Symposium on cooperative phenomena** (Session KA: speakers, V. F. Weisskopf, David Pines, N. M. Hugenholtz) and a **Symposium on applied plasma physics** (Session HA: P. R. Bell, Keith Boyer, T. H. Stix, and Edward Teller).

Our **Division of Electron Physics** has organized a Symposium on the Physics of the Upper Atmosphere, scheduled for Wednesday afternoon (Session FA): the speakers are Robert Jastrow, Herbert Friedman, and Sydney Chapman.

**Three hundred and fifty-nine contributed papers** are distributed among thirty-two sessions. (Last year we had 367 and the year before that 376). The proper arranging of theoretical papers having long ago exceeded the competence of the Secretary, he now regularly invokes the sagacious aid of theorists, and this year it is N. M. Kroll who has assumed the difficult and delicate task. Similarly the organization of the sessions allocated to the Panel Room (and the one on Saturday afternoon assigned to the Grand Ballroom) has been achieved by the Deputy Secretary, who it will be noted has done away with the caption "reactions of transmutation," so long a feature of these programmes. It is somewhat interesting to watch the ebb and flow of topics from year to year. Semiconductors have lost ground; "strange particles," other than $K$-mesons, are missing, owing we think to the suction of the recent specialized conference at Gatlinburg; ferroelectrics have graduated to a whole session of their own, and so would plasma physics have done but that we had to transfer to it two papers from what would otherwise have been an overlarge session on fluid dynamics; cosmic rays have gained; but the most massive change is the upward bound of theoretical physics from 65 at the last Annual Meeting to 80 (these figures not including occasional papers placed in sessions mainly experimental).

The **Business Meeting of the American Physical Society** will be held at 4:45 P.M. on Wednesday in the Grand Ballroom of the New Yorker—same day and same hour as at each of the last two Annual Meetings.

The **Council of the American Physical Society** will convene on Tuesday, January 27, at 10:30 A.M. in the building of the American Institute of Physics, 335 East 45th Street, unless contrary notice is sent to its members.

The American Institute of Physics will conduct a **Placement Service Register** on the 5th floor of the New Yorker, January 28–31, 1959. The Register will be open until 9:00 P.M., Wednesday, Thursday, and Friday evenings and until noon on Saturday.

**Post-deadline ten-minute papers** pertaining to very recent achievements of very special importance will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Friday, January 23. The titles of such as are accepted will be displayed on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule at the end of Session U unless another indication is made on the blackboard. The abstracts will not be published.

**Preliminary announcements of the Austin and Cambridge meetings** appear on page 75 of this Bulletin. On page 87 are published the **calendar of meetings and deadlines** up to the end of next summer, and below it the **rules and instructions for the preparation of abstracts** which we commend to the attention of every member. We salute those who have adapted themselves to the usage of the **Bulletin** by submitting abstracts with the title in ordinary type, then the author's name in capitals, and the author's institution in lower-case underscored. The most frequent sin at present is that of typing an abstract in two or more paragraphs. We do not understand why this is done.

**Errata** pertaining to the contents of this issue will be published in a later issue of this Bulletin if received not later than Monday, February 2, by Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Do not send in your abstracts marked with corrections! Write out the corrections in the form "Instead of . . . read. . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

# EPITOME OF THE 1959 ANNUAL MEETING

(Personal names are those of invited speakers.)

## Wednesday Morning

| | | |
|---|---|---|
| 10:30 | A. | Scharff-Goldhaber, Barnes. Grand. |
| 10:00 | B. | Cryogenics; Tinkham. Boston. |
| 10:30 | BA. | Cosmic rays. Terrace. |
| 9:45 | C. | Nuclear structure. Panel. |
| 10:30 | CA. | Hyperfine structure, nuclear magnetic resonance. New Orleans. |
| 9:45 | D. | Theoretical physics I, largely atomic theory. Empire. |

## Wednesday Afternoon

| | | |
|---|---|---|
| 2:00 | E. | Theoretical physics II; statistical theory, general relativity. Empire. |
| 2:00 | EA. | Nuclear energy levels. Panel. |
| 2:00 | F. | Fluid dynamics I: Business Meeting of Division of Fluid Dynamics. Boston. |
| 2:00 | FA. | Division of Electron Physics: Physics of upper atmosphere. Jastrow, Friedman, Chapman. Business Meeting of Division. Grand. |
| 2:15 | G. | Paramagnetic resonance; masers; semiconductors I. Governor Clinton. |
| 2:00 | GA. | Pions. Rainwater. Terrace. |

## Wednesday Afternoon

4:45 Business Meeting of the American Physical Society. Grand.

## Thursday Morning

| | | |
|---|---|---|
| 9:45 | H. | Walker, Cool; *K* mesons. Terrace. |
| 9:45 | HA. | Symposium on applied plasma physics: Teller, Bell, Boyer, Stix. Grand. |
| 9:45 | J. | Semiconductors II. Governor Clinton. |
| 9:45 | JA. | Theoretical Physics III, largely quantum mechanics and field theory. Empire. |
| 10:00 | K. | Fission; neutrons. Panel. |
| 10:00 | KA. | Symposium on cooperative phenomena: Weisskopf, Hugenholtz, Pines. |

## Thursday Afternoon

2:00 L. Joint Ceremonial Session: Beams, Kirkpatrick, Townes. Manhattan Center.

## Friday Morning

| | | |
|---|---|---|
| 9:45 | M. | Neutron spectroscopy I. Panel. |
| 9:45 | MA. | Tollestrup, Crowe, Plano, Primakoff. Grand. |
| 10:00 | N. | General solid-state physics. Boston. |
| 10:00 | NA. | Smith, Pipkin, Hardy, Burgess. Governor Clinton. |
| 9:45 | P. | Theoretical physics IV, mostly strange particles. Empire. |
| 9:45 | PA. | Fluid dynamics II; plasma physics. Terrace. |

## Friday Afternoon

| | | |
|---|---|---|
| 2:00 | Q. | Bube, Ludwig, Portis. Empire. |
| 2:00 | QA. | Dirac, Marshak, Goldberger. Grand. |
| 2:00 | R. | Neutron spectroscopy II. Panel. |
| 2:15 | RA. | Mark, Crawford, Allin, Van Kranendonk. Terrace. |
| 2:15 | S. | Electron physics. Boston. |
| 2:00 | SA. | Metals; dislocations; radiation damage. Governor Clinton. |

## Friday Evening

7:00 Banquet of the American Physical Society and the AAPT; Dryden, AEC moving picture. Terrace.

## Saturday Morning

| | | |
|---|---|---|
| 9:30 | T. | Theoretical physics V: nuclear theory, pion theory. Empire. |
| 10:05 | TA. | Rosen, Paul, Gove, Freeman. Grand. |
| 10:00 | U. | Heavy-ion bombardment; post-deadline papers, if any. Panel. |
| 9:30 | UA. | Magnetism. Governor Clinton. |
| 9:30 | V. | Van de Graaff; accelerators. Terrace. |
| 9:30 | VA. | Beta emitters. Boston. |

## Saturday Afternoon

| | | |
|---|---|---|
| 1:45 | W. | Theoretical physics VI: nuclear theory, general topics. Empire. |
| 1:45 | WA. | Scattering and polarization of electrons and nucleons. Grand. |
| 1:45 | X. | Ferroelectrics. Governor Clinton. |
| 1:45 | XA. | Apparatus of nuclear physics; general nuclear physics. Panel. |
| 1:45 | Y. | DuMond; general physics. Terrace. |
| 1:45 | Z. | Spectroscopy. Boston. |

# PROGRAMME

## WEDNESDAY MORNING AT 10:30

Grand Ballroom

(L. J. HAWORTH presiding)

### *Invited Papers in Nuclear Physics*

**A1. Recent Work on Even-Even Nuclei.** GERTRUD SCHARFF-GOLDHABER, *Brookhaven National Laboratory.* (30 min.)

**A2. Angular Correlation of Beta Particles and Neutrinos in the Decay of Lithium 8.** C. A. BARNES, *California Institute of Technology.* (30 min.)

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## WEDNESDAY MORNING AT 10:00

Boston Room

(M. W. ZEMANSKY presiding)

### *Cryogenics*

**B1. Heat Capacity of Uranium Tetrafluoride from 1.3 to 20°K.*** J. H. BURNS, D. W. OSBORNE, AND E. F. WESTRUM, JR.,† *Argonne National Laboratory.*—The heat capacity of uranium tetrafluoride has been determined from 1.3 to 20°K in an isothermal calorimeter employing a carbon resistance thermometer calibrated by gas and vapor pressure thermometers. The results of this determination were combined with previoulsy reported values of the heat capacity above 5°K[1] to obtain the following thermodynamic functions. At 298.15°K, the values of $S^0$, $(H^0-H_0^0)/T$, and $-(F^0-H_0^0)/T$ are 36.25, 18.08, and 18.18 cal mole$^{-1}$ deg$^{-1}$, respectively. The lattice heat capacity was assumed to be equal to that of thorium tetrafluoride[2] in order to resolve the magnetic contribution to the heat capacity of uranium tetrafluoride. A Schottky-type anomaly occurs in the magnetic heat capacity at 6.5°K, and is presumably due to the crystalline field splitting of the electronic energy levels.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at the University of Michigan.
[1] Osborne, Westrum, and Lohr, J. Am Chem. Soc. **77**, 2737 (1955).
[2] Lohr, Osborne, and Westrum, J. Am. Chem. Soc. **76**, 3837 (1954).

**B2. Comparison between Theoretical and Experimental Values of the Electronic Specific Heat in the Superconducting State.** H. A. BOORSE AND A. HIRSHFELD, *Columbia University.*—The Bardeen, Cooper, Schrieffer (BCS) theory of superconductivity provides an expression for the temperature variation of the reduced superconducting electronic specific heat $Ces/\gamma T_c$, under the condition that $\beta\epsilon_0 \gg 1$. ($\beta = 1/kT$ and $\epsilon_0$ is the value of the energy gap at temperature $T$.) In the range of inverse reduced temperatures $1/t = 2.6$ to 6.4, the BCS expression may be closely approximated *empirically* by the relation $Ces/\gamma T_c = ae^{-b/t}$, with $a = 8.5$ and $b = 1.44$. This empirical exponential gives values in good agreement with experiment, although the $a$ and $b$ values are different for the different superconductors. In the range $1/t = 7$ to 11.5, the BCS theoretical expression also may be closely approximated by the foregoing exponential, provided that now $a = 26$ and $b = 1.62$. In view of the good agreement with the empirical exponential found in the lower range of $1/t$ values, it might be expected that on the basis of the $\beta\epsilon_0$ criterion, the agreement would be better in this higher range. The experimental data currently available do not bear out this expectation and in some cases there is marked departure from exponential behavior. These recent results will be presented and discussed.

**B3. Noise in Superconducting Tantalum.** D. C. BAIRD, *Royal Military College of Canada.*—The problem of the origin of the noise observed in hard superconductors in the intermediate state has been studied by continuous recording of the potential across a tantalum wire carrying a current greater than the critical value. The noise pattern becomes clarified by the use of short specimens and the noise is seen to arise from spontaneous transitions between discrete resistance values. It is further observed that the intermediate state resistance of a short section of wire consists only of discrete values and is not a smooth function of current and temperature. These resistance values depend on the specimen and are permanent. The results can be interpreted in terms of an intermediate state structure which is coarse compared with the wire dimensions and which has interphase boundaries occupying preferred positions in the metal lattice.

**B4. Frequency Dependence of the Surface Resistance of Superconducting Tin in the Millimeter Wavelength Region.** RAYMOND KAPLAN, A. H. NETHERCOT, AND H. A. BOORSE; *Columbia University.*—The ratio of superconducting to normal surface resistance of tin has been measured between 17 kMc/sec and 77 kMc/sec from 1.5°K to 3.0°K. From these data the surface resistance ratio has been determined as a function of frequency and temperature. A formula for this ratio has been obtained by Serber (unpublished) on the basis of the London two-fluid model of superconductivity and the Reuter-Sondheimer theory of the anomalous skin effect. If the electronic mean free path is chosen as $(8\pm2)\times10^{-3}$ cm and the Fermi velocity as $(1.3\pm0.2)\times10^{8}$ cm/sec, then the data and the formula are in good agreement. This agreement is not sensibly affected by any reasonable choice of the penetration depth.

**B5. Oscillations in the Ettinghausen-Nernst and Thermoelectric Effects in Zinc at Low Temperatures.*** C. J. BERGERON, C. G. GRENIER, AND J. M. REYNOLDS, *Louisiana State University.*—Measurements in a zinc single crystal of the Ettinghausen-Nernst effect and the thermoelectric effect show de Haas van Alphen type oscillations. The period of these oscillations in 1/H is the same as that of the Hall effect

and magnetoresistance. Since neither of these effects possess a monotonic component they lend themselves very easily to harmonic analysis.

* Supported by the Office of Ordnance Research, U. S. Army.

**B6. Oscillations in the Isothermal Galvanomagnetic Effects in Zinc at Low Temperature.*** C. G. GRENIER, C. J. BERGERON, AND J. M. REYNOLDS, *Lousiana State University.*—Careful study of the amplitude of the oscillations of the Hall effect and magnetoresistance in zinc as a function of the temperature showed a normal behavior as in the de Haas van Alphen effect. An earlier report[1] pointed out a decrease of amplitude from 4.2° to 1.7° with a small change in phase. This anomalous effect was found to be due to the superposition upon the Hall effect of a small Ettinghausen-Nernst effect. It was also necessary to correct the magnetoresistance for a small thermoelectric voltage oscillation. An extensive study of the harmonic content of the oscillation, as a function of temperature and magnetic field, has been made. The abnormally large amplitude of the second harmonics remains unexplained and seems correlated to the small amplitude of the second harmonics in the de Haas van Alphen effects.

* Supported by the Office of Ordnance Research, U. S. Army.
[1] Ali, Grenier, and Reynolds, Bull. Am. Phys. Soc. Ser. II, 3, 304 (1958).

**B7. Low-Temperature Helium Pulse Ionization Chamber.** S. H. HANAUER, J. W. T. DABBS, AND L. D. ROBERTS, *Oak Ridge National Laboratory.*—Recent measurements[1,2] using helium as a counting gas have shown that $W$ (average energy to form an ion pair) is very sensitive to traces of foreign gases. For this investigation, a small, gridded, parallel-plate ionization chamber was operated in helium vapor at 2–2.6°K, where all materials except helium have vapor pressures less than $10^{-13}$ mm Hg. The feasibility of helium vapor pulse chambers was demonstrated by Abele, Zedler, and Roberts[3]; however, they reported no detailed measurements. Alpha particles from $Am^{241}$ were collimated with paths approximately parallel to the electrodes.[4] The data were normalized using 90% A, 10% $CH_4$ at 300°K. The rise time, corrected for amplifier clipping, was ~10–20 $\mu$, with a grid-plate spacing of 0.95 cm, and appeared to vary slowly when electrode potentials were varied by a factor 30. Extrapolating the pulse-height data to zero gas density, and using $W_{A-CH_4}=26$ ev,[5] we find $W_{He} \leq 46\pm4$ ev. This agrees well with $W_{He}$ given by others.[1,2]

[1] W. P. Jesse and J. Sadauskis, Phys. Rev. 90, 1120 (1953).
[2] T. E. Bortner and G. S. Hurst, Phys. Rev. 93, 1236 (1954).
[3] Abele, Zedler, and Roberts, Rev. Sci. Instr. 26, 521 (1955).
[4] The assistance of G. W. Parker with source preparation is gratefully acknowledged.
[5] Moe, Bortner, and Hurst, J. Phys. Chem. 61, 422 (1957).

**B8. Thickness of the He II Film *vs* Height to 40 cm.*** O. T. ANDERSON,† D. H. LIEBENBERG, AND J. R. DILLINGER, *University of Wisconsin.*—The thickness $d$ of the He II film at 1.40°K *vs* height $h$ to 40 cm has been measured by an optical method. The vertical distance from the level of liquid supplying the film to a stainless steel mirror mounted on the end of a brass rod is $h$. The thickness of the film on the mirror was measured. Results agree better with an expression of the form $d=kh^{-\frac{1}{3}}$ than with $d=k'h^{-\frac{1}{2}}$ or $h=(a/d)^3+(b/d)^2$. The thickness $k$ at a height of 1 cm, was found to be about 288 A. The pressure exerted on the film on the mirror will decrease slightly with increasing $h$ due to gravitational effects in a vertical gas column. Arrangements were made whereby the distance from the mirror to the level of liquid supplying the film on the mirror could be changed abruptly from one value to a widely different one with negligible change in pressure in the region of the mirror. An abrupt change in $d$ was observed to accompany this abrupt change in $h$. Therefore, it may not be possible to account for the contour of the film by considering it to be an adsorbed film subjected to a pressure which varies with $h$ in the vertical gas column.

* This work was supported in part by the Wisconsin Alumni Research Foundation and the U. S. Atomic Energy Commission.
† Present address: International Business Machines Corporation, Poughkeepsie, New York.

**B9. Coefficient of Thermal Expansion and Entropy of Liquid $He^3$ under Pressure at Temperatures below 1°K.*** D. F. BREWER AND J. G. DAUNT, *The Ohio State University.*—The coefficient of thermal expansion $\alpha$ of pure $He^3$ in the temperature range 0.15°K to 1.1°K has been determined by measuring the change in temperature on adiabatic expansion of the liquid and by use of the relation $\alpha \approx (C_p/VT)(\Delta T/\Delta p)_s$. An adiabatic calorimeter was used, as in the previously reported[1,2] measurements of $C_p$, and the temperature changes were observed for pressure drops in steps of 2 atmospheres. $\alpha$ is negative below a temperature $T_0$, which increases monotonically with pressure. $T_0=1.1$°K at 20 atmos, and $T_0\approx0.51$°K at the saturated vapor pressure; the latter value is an extrapolated one and may not be very accurate. From these results the entropy changes on isothermal compression at 0.6°K have been calculated and used in combination with our previous evaluation of $S$ at the saturation pressure[1] and our data on the specific heat under pressure[2] to compute $S$ as a function of $T$ along various isobars up to 15.6 atmos. Since $(\partial S/\partial p)_T$ is always positive below about 0.51°K, adiabatic compression of the liquid at these lower temperatures would produce cooling. The results show that the coolings would not be great enough to represent a useful method of obtaining lower temperatures.

* This work was supported by a Grant-in-Aid from the National Science Foundation.
[1] Brewer, Sreedhar, Kramers, and Daunt, Phys. Rev. 110, 282 (1958).
[2] Brewer, Sreedhar, and Daunt, Bull. Am. Phys. Soc. Ser. II, 3, 399 (1958).

## *Invited Paper*

**B10. Experimental Consequences of the Energy Gap in Superconductors.** M. TINKHAM, *University of California, Berkeley.* (30 min.)

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## WEDNESDAY MORNING AT 10:30

## Terrace Room

## (E. O. SALANT presiding)

## *Cosmic Rays*

**BA1. Gap Length Distribution Measurements.*** R. A. MOLLISON, L. J. GALLAHER, AND C. A. RANDALL, *Ohio University.*—A method has been developed for determining the charge of relativistic particles in cosmic-ray emulsions based on gap counting and gap length measurements.[1] The method stems from the fact that the slope of the gap length

distributions histogram (log plot) is equal to the reciprocal of the average gap length. Both quantities are equal to const $xZ^2$ and are used as a cross check. Good charge resolution was attained in the region $1 \leq Z \leq 8$ for particles clearly having velocities $\beta \approx 1$. Measurements were made in G-5 emulsions that had been exposed at high altitudes. Methods of measuring and counting gaps, criteria for selecting $\beta \approx 1$ tracks, and calibration techniques will be presented.

* Supported in part by the National Science Foundation and the Ohio University Fund, Inc.
[1] P. H. Fowler and D. H. Perkins, Nuovo cimento Suppl. 4, 238 (1956).

**BA2. Analysis of Cosmic-Ray-Produced Helium in a Small Iron Meteorite.*** JOHN H. HOFFMAN AND A. O. NIER, *University of Minnesota.*—The $He^3$ and $He^4$ contents throughout a slice cut from a small iron meteorite, Keen Mountain,[1] (average radius 5 cm) have been measured and plotted in a manner similar to that previously reported for the large (25-cm radius) Grant meteorite.[2] The helium contents were found to be constant within 2% of $2.2 \times 10^{-6}$ scc/g and $8.0 \times 10^{-6}$ scc/g, respectively, throughout the slice. The $He^3/He^4$ ratio is, therefore, about 0.28. Employing the results of the Grant contour analysis, i.e., cosmic-ray interaction cross sections in iron, $He^3/He^4$ ratios produced by primary and secondary interactions, etc., and the measured $He^3/He^4$ ratio in Keen Mountain, the ratio of post- to pre-atmospheric radii of Keen Mountain was calculated to be 0.2. This value is considerably lower than the corresponding value for Grant,[2] perhaps suggesting a higher geocentric velocity for Keen Mountain than for Grant.[3]

* Research supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Dr. E. P. Henderson, U. S. National Museum, Washington, D. C., provided the samples. Cutting was done at the Battelle Memorial Institute, Columbus, Ohio.
[2] John H. Hoffman and A. O. Nier, Bull. Am. Phys. Soc. Ser. II, 3, 221 (1958); Phys. Rev. (to be published).
[3] G. R. Martin, Geochim. et Cosmochim. Acta 3, 288 (1953).

**BA3. Cloud Chamber Measurements on Jets.*** W. B. FRETTER AND L. F. HANSEN, *University of California, Berkeley.*—Nuclear interactions of cosmic rays in carbon at sea level have been analyzed in a cloud chamber in which accurate momentum and ionization measurements are possible. Pions can be distinguished from protons up to 20 Bev/$c$, and momenta measured up to 30 Bev/$c$. The interactions are attributed to pion-nucleon and nucleon-nucleon interactions with energies in the laboratory of from $10^{10}$ ev to $10^{12}$ ev. Sixty-seven such nuclear interactions have been analyzed and results will be presented on energy distributions, multiplicities of pions, and heavier particles. In the energy range $5.10^{11}$–$10^{12}$ ev the average multiplicity of charged particles is found to be 5.6 per event.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**BA4. Partial Temperature Effect on Obliquely Incident Cosmic Rays.*** K. MAEDA, *University of Nebraska.*—Extending previous calculations of the temperature effect upon vertically incident $\mu$ mesons,[1] similar expressions for atmospheric effects are given for obliquely incident particles. The basis of these calculations is the rigorous solution of the diffusion equations of cosmic-ray mesons in the standard atmosphere. The results are compared with those of Dorman,[2] which were based upon a different model of the atmosphere and which neglected to take into account the effect of earth curvature upon the zenithal dependence of particle path length through the atmosphere. The present discussion includes also the heretofore neglected effect of geomagnetic field, which causes the deflection of the paths of the $\mu$ mesons and sensibly alters the atmospheric path length. An estimate of these contributions for large zenith angle of incidence and a new correction scheme for atmospheric effects will be discussed.

* Work supported in part by University of Nebraska Research Council and National Science Foundation (IGY).
[1] K. Maeda and M. Wada, J. Sci. Research Inst. (Tokyo) 48, 71 (1954).
[2] L. I. Dorman, *Cosmic Ray Variations* (State Publishing House, Moscow, 1957); translation supplied by U. S. Air Force Technical Documents Liaison Office.

**BA5. Search for a Meson of Mass 550$m_e$.** E. P. HINCKS, *Chalk River Laboratories.*—A search is being made for long-lived charged mesons of mass 550 $m_e$[1] in the cosmic radiation near sea level. Single particles of known range are selected by a "hodoscoped" Geiger counter telescope. For each particle the velocity is determined from the light intensity in each of three Čerenkov counters and $dE/dx$ is measured with a liquid scintillator. The selection of a given region of the mass spectrum for study is achieved by adjusting absorbers between the counters. The sensitivity is described by the rate of stopping of muons with the absorbers appropriate to mass 550 and is ~3000 per day, while the resolution is sufficient to completely separate mass 550 from the muon tail. Preliminary results show that the upper limit of the ratio of the numbers of mass 550 particles to muons in the same range interval is $\sim 5 \times 10^{-4}$. This is similar to limits reported recently[2] by several other workers.

[1] Reported to exist at mountain altitudes by Alikhanian *et al.*, Zhur. Eksptl. i Teoret. Fiz. 31, 955 (1956); translation: Soviet Phys. JETP 4, 817 (1957).
[2] At the 1958 Annual International Conference on High-Energy Physics at CERN.

**BA6. Theory of the Cosmic-Ray Radiation Belt: Altitude, Latitude, and Energy Distribution.*** S. F. SINGER, H. GRIEM, AND R. C. WENTWORTH, *University of Maryland.*—The intensity of the radiation follows from a balance of the rates of injection into trapped orbits with the rate of removal from such orbits. A discussion of the lifetime of electrons and protons in the exosphere and of the possible injection mechanisms indicates that cosmic-ray albedo neutrons should be the dominant source at low and intermediate latitudes; they provide decay protons with energy up to a few hundred Mev.[1] The lifetime of these protons is mainly determined by collision loss. Angle scattering is negligible and the intensity therefore can be obtained from the production rate by integration over the orbits. Here we calculate directional and omnidirectional differential and integral intensities for latitudes up to 45° and altitudes to two earth radii. The proposed mechanism may be adequate to explain the observed intensities except for the fringe regions where, probably, injection from solar corpuscular beams is the dominant production mechanism and adds an auroral (soft) radiation belt.

* Assisted by the Air Force Office of Scientific Research.
[1] S. F. Singer, Phys. Rev. Letters 1, 171, 181 (1958).

**BA7. Lifetimes of Trapped Auroral Radiation Belt Particles.*** R. C. WENTWORTH, W. M. MACDONALD, AND S. F. SINGER, *University of Maryland.*—Trapping of solar protons and electrons in the earth's magnetic field has been discussed in connection with a theory of magnetic storms.[1] A fraction of the trapped particles are accelerated to auroral energies by hydromagnetic waves[2] leading to a characteristic velocity spectrum. Here we discuss the effective lifetime of these particles as given by the effects of collisions with atoms and ions in the earth's outer atmosphere. We use the Fokker-Planck equation for Coulomb interactions[3] and the usual Boltzmann equation for neutral atom collisions. This lifetime is compared with lifetime limits set by charge exchange and by scattering out by hydromagnetic waves, and is used to derive radiation intensities in the auroral (soft) radiation belt.

* Assisted by the Air Force Office of Scientific Research and by the Air Force Geophysics Research Directorate.
[1] S. F. Singer, Trans. Am. Geophys. Union 38, 175 (1957).
[2] S. F. Singer, Bull. Am. Phys. Soc. Ser. II, 3, 40 (1958).
[3] Rosenbluth, MacDonald, and Judd, Phys. Rev. 107, 1 (1957).

**BA8. Heavy Primary Cosmic Rays from Texas Daytime Flights.** O. B. YOUNG AND H. Y. CHEN, *Southern Illinois University.*—This report includes the results from 9 balloon flights at G.M. latitude 41°N of altitude range from 70 000 to 100 000 ft. Only primaries of $Z \geq 10$ considered. 2410 tracks are involved in Ilford G-5 and G-0 emulsion exposures. Given are the charge spectrums, flux, mean free paths, and angular distributions.

**BA9. Cosmic-Ray μ-Meson Spectrum.*** BYRON P. ROE AND SEINOSUKE OZAKI,† *Cornell University.*—The spectrum of cosmic-ray muons of energies between 2 and 120 Bev has been measured in the vertical direction and at 68° to the vertical direction with the Cornell magnetic spectrometer at Ithaca, New York. (Latitude 42°, elevation 900 ft.) At energies above 10 Bev, the differential spectrum can be approximated by a power law $E^{-\alpha}$ where $\alpha = 2.70 \pm 0.06$ in the vertical direction and $\alpha = 2.34 \pm 0.08$ at an angle of 68° to the vertical direction, the intensities at 0° and 68° being equal in the neighborhood of 100 Bev. In the range from about 2 to 10 Bev the spectrum may be approximated by a curve of the form $(E+E_0)^{-\alpha}$ where $E_0 = 3$ Bev, $\alpha = 2.7$ in the vertical direction and $E_0 = 6$ Bev, $\alpha = 2.35$ at 68° to the vertical direction. The results at 0° are in agreement with previous data, but have better statistical accuracy. The results at 68° are new. Comparison with underground measurements indicates that there is no large radiative or nuclear source of energy loss.

* This work was supported by a grant from the National Science Foundation.

† Fulbright Fellow, on leave from Osaka City University, 1955–1958.

**BA10. Atmospheric Penetration by 10-Mev Electrons and 35-Mev Protons.** R. M. RHODES, *Convair, San Diego* (introduced by J. W. Bond, Jr.).—The trajectories of 10-Mev electrons and 35-Mev protons through the atmosphere have been studied. An exponential atmosphere was assumed and a value of magnetic field appropriate to the auroral zone chosen. The penetration depths of the atmosphere for the particles as a function of pitch angle and omnidirectional counting rates as a function of altitude were computed; graphs of these will be presented. A general survey of Liouville's theorem revealed a special case of importance in which the theorem holds to a high degree of approximation, and a study of pitch angle as a function of altitude performed.

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## WEDNESDAY MORNING AT 9:45

## Panel Room

## (C. E. MANDEVILLE presiding)

### *Nuclear Structure*

**C1. $He^3$ and $He^4$ Induced Coulomb Excitation.** D. A. BROMLEY, J. A. KUEHNER, AND E. ALMQVIST, *Chalk River Laboratories.*—Thick target radiation yield ratios[1] have been measured for $He^3$ and $He^4$ induced Coulomb excitation of each of the 110- and 197-kev levels of $F^{19}$, the 446-kev level of $Na^{23}$, the 160-kev level of $Ti^{47}$, and the 126-kev level of $Mn^{55}$ at corresponding (equal $\xi$) energies. For the $E2$ transitions a mean ratio of the $He^3$ to $He^4$ induced yields of $0.63 \pm 0.02$ was found, independent of incident energy in the range 1.0 to 2.5 Mev in agreement with the calculated value of 0.64. In contrast, in the case of the 110-kev $E1$ transition in $F^{19}$, the the ratio $R_{E1}$ drops from a value of $0.93 \pm 0.10$ at $E_{He^3} = 1.0$ Mev to $0.72 \pm 0.12$ at $E_{He^3} = 1.75$ Mev; the corresponding theoretical prediction is 0.76. The large quoted errors reflect the difficulties involved in determining the 110-kev yields in the presence of the more intense 197-kev radiation which has Compton back scattered quanta of 110 kev. It has not been possible to make similar measurements on other $E1$ transitions as yet; these are required to decide whether the enhanced $R_{E1}$ values are peculiar to the $F^{19}$ states involved or to the use of $He^3$ and $He^4$ ions. The energy variation of $R_{E1}$ is suggestive of nuclear inelastic alpha scattering contributions.

[1] J. H. Bjerregaard and T. Huus, Phys. Rev. **94**, 204 (1954).

**C2. Nuclear Reactions in Light Nuclei Induced by $He^3$ Ions.*** SAMUEL S. MARKOWITZ AND JANE M. HALL, *University of California, Berkeley.*—Beams of $He^3$ ions have recently been accelerated at the Crocker 60-in. cyclotron to a maximum energy of 17.7 Mev and at the HILAC to a maximum energy of 31.2 Mev. Using dilute $He^3$ in $He^4$ gas mixtures (about 4% $He^3$), we obtained an internal beam intensity of 1 μa of doubly-charged $He^3$ at the cyclotron and about 0.01 μa of singly-charged $He^3$ at the HILAC. Excitation functions have been measured by stacked-foil experiments for the following reactions $Al^{27}(He^3,2\alpha)Na^{28}$, $Al^{27}(He^3,3\alpha)F^{18}$, $Al(^{27}He^3,\alpha 2p)Na^{24}$, and $Be^9(He^3,n)C^{11}$. The low binding energy of the $He^3$ nucleus, 7.7 Mev (compared with 28.2 Mev for $He^4$), leads to these calculated "$Q$" values for the above reactions: (−1.9 Mev), (−10 Mev), (−11 Mev), and (+7.7 Mev), respectively. The $P^{30}$ compound nucleus formed in the $Al^{27}$ reactions with 31.2 Mev $He^3$ ions is excited to about 44 Mev. The $C^{12}(He^3,\alpha)C^{11}$, and $C^{12}(He^3,d$ and $np)N^{13}$ excitation functions previously measured[1] from 13 to 21 Mev, have been extended to 31.2 Mev. Direct interaction processes such as stripping and pickup will be discussed.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] D. R. F. Cochran and J. D. Knight, Bull. Am. Phys. Soc. Ser. II, 3, 323 (1958).

**C3. Scattering of 21.6-Mev Deuterons by $Ni^{58}$, $Ni^{60}$, $Cu^{63}$, and $Cu^{65}$.*** J. L. YNTEMA AND B. ZEIDMAN, *Argonne National Laboratory.*—The differential cross section for the elastic scattering of 21.6-Mev deuterons by $Ni^{58}$, $Cu^{63}$, and $Cu^{65}$ was measured from 18° to 110° in 2° steps and by $Ni^{60}$ from 41° to 117°. The experiment was done in the Argonne 60-in. scattering chamber. Two NaI(Tl) crystals were used for the detection and particle identification. The positions of the minima and maxima of the diffraction pattern show small shifts. The difference in position for $Ni^{58}$ and $Ni^{60}$ is the same as those for $Cu^{63}$ and $Cu^{65}$ to within about 10%. The shift between $Cu^{63}$ and $Ni^{60}$ appears to be approximately 1.5 times the shift between $Ni^{58}$ and $Ni^{60}$. The angular distribution of deuterons scattered inelastically from the 1.45-Mev level of $Ni^{58}$ has been measured. The cross section is peaked strongly in the forward direction and shows minima near 30°, 56°, and 96°. The angular distribution of the 1.3-Mev groups in $Cu^{63}$ and $Cu^{65}$ shows a behavior very similar to that of the 1.45-Mev level in $Ni^{58}$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**C4. $(p,d)$ Reactions at 23 and 19 Mev.** C. D. GOODMAN AND J. B. BALL, *Oak Ridge National Laboratory.**—A study of the deuteron energy distributions at several angles from proton bombardment of medium and heavy weight elements has been made using a $dE/dx$, $E$ identification of the deuterons with a NaI(Tl) energy detector. As noted in a previous survey,[1] the deuteron spectra are peaked near the maximum energy. They show pronounced gross structure very much broader than individual level spacings, with element to element regularities in the structure. Comparison of the spectra taken at 23 and at 19 Mev show that these regularities are not a function of the kinetic energy of the deuteron; they are a function either of the excitation energy of the residual nucleus or of the difference between the initial and final channel energy. Cohen and Mosko[2] found striking evidence for the latter in lead isotopes and bismuth. The present data from other targets, however, do not rule out the former as the important parameter. Additional spectra from targets chosen to have widely different $(p,d)$ $Q$ values should clarify this point.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.
[1] B. L. Cohen and A. G. Rubin, Bull. Am. Phys. Soc. Ser. II, **3**, 211 (1958).
[2] B. L. Cohen and S. W. Mosko, Phys. Rev. **106**, 995 (1957).

**C5. Gross Structure Regularities in Energy Spectra of Protons from $(p,p)$ Reaction.*** B. L. COHEN, K. S. QUISENBERRY, J. B. MEAD, AND R. E. PRICE, *University of Pittsburgh.*—Energy spectra of protons from $(d,p)$ stripping reactions induced by 15-Mev deuterons in various heavy elements were measured with scintillation detectors (400-kv resolution) and by magnetic analysis (70-kv resolution). When the spectra are plotted *vs* proton energy or $Q$ values (rather than *vs* final nucleus excitation energy), many features of the gross structure are very regular in both energy and cross section from element to element. For example, $_{82}$Pb, $_{79}$Au, $_{78}$Pt, $_{74}$W, and $_{73}$Ta have sharp peaks at $Q=2.0$ Mev, and broad peaks at $Q\sim0.3$ Mev. $_{79}$Au, $_{78}$Pt, $_{74}$W, $_{73}$Ta, $_{50}$Sn, $_{49}$In, $_{48}$Cd, $_{47}$Ag, $_{46}$Pd, $_{45}$Rh, $_{42}$Mo, $_{41}$Nb, and $_{40}$Zr all have strong peaks at about $Q=3.8$ Mev which occur regularly at $\sim0.3$ Mev higher energy in odd than in even elements. Although ground-state transitions in some nuclei contribute to these peaks, they are not principal contributors; and ground-state transitions which fall at energies away from these peaks are not strongly excited. The energies of the various peaks do not shift with nuclear radius as is expected for single particle levels in a potential well (which successfully explain neutron cross sections.[1])

* Work done at the Sarah Mellon Scaife Radiation Laboratory assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Feshbach, Porter, and Weisskopf, Phys. Rev. **96**, 484 (1954).

**C6. Gross Structure in Proton Spectra from $(d,p)$ Reactions.*** J. P. SCHIFFER, L. L. LEE, JR., AND B. J. RAZ, *Argonne National Laboratory.*—Systematic structure in the proton spectra emitted in the $(d,p)$ reaction from target elements between Ti and Cu have now been observed with deuteron energies of 4, 10, and 22 Mev.[1] Angular-distribution measurements have allowed a classification of the observed structure. Peaks in the spectra, corresponding to single-particle states of a neutron (or maxima in the neutron strength function) with orbital angular momentum $l=0$, 1, 2, 3, and 4 have been identified. Spin-orbit effects have been observed. The relative intensities of various maxima have been used to yield information regarding the ground-state configurations of the target nuclei.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Schiffer, Lee, Yntema, and Zeidman, Phys. Rev. **110**, 1216 (1958).

**C7. Gross Structure of $(n,p)$ Spectra Near $Z=50$.*** R. A. PECK, JR., *Brown University.*—The $(n,p)$ reaction has been studied for target nuclei $_{45}$Rh$^{103}$, $_{49}$In$^{115}$, $_{50}$Sn$^{116}$, and $_{50}$Sn$^{120}$ by the emulsion method. Reaction angles 0°–45° are covered and 2000 or more measured tracks for each spectrum are being processed. The study is a companion to that of In$^{115}(d,p)$In$^{116}$ and Sn$^{120}(d,p)$Sn$^{121}$ which failed to show the anticipated single particle structure,[1] although gross structure has been clearly demonstrated[2] in $(d,p)$ reactions in the neighborhood of $Z=20$.

* Supported in part by the U. S. Atomic Energy Commission.
[1] R. A. Peck, Jr., and J. Lowe, Bull. Am. Phys. Soc. Ser. II, **3**, 211 (1958).
[2] J. P. Schiffer and L. L. Lee, Jr., Bull. Am. Phys. Soc. Ser. II, **3**, 211 (1958).

**C8. $(p,\alpha)$ Reactions Induced by Protons in the Energy Range of 11–23 Mev.** C. B. FULMER AND C. D. GOODMAN, *Oak Ridge National Laboratory.**—An earlier study of $(p,\alpha)$ reactions induced by 23-Mev protons[1] has been extended by observing the outgoing alpha particles from nuclear reactions induced by protons of various energies between 11 and 23 Mev in numerous elements throughout the periodic table. Alpha-energy distributions and absolute differential cross sections were measured at 90 deg. $(p,\alpha)$ cross sections decrease with increasing atomic number, increase with proton energy, and increase with $[Q(p,\alpha)-Q(p,n)]$; however, variations with proton energy and $Q$ values are different from those predicted if Coulomb barriers encountered by charged particles bombarding ground-state nuclei are assumed. Agreement between experiment and theory can be obtained by assuming lowered Coulomb barriers for the excited compound nuclei. The maxima of the alpha-energy distributions do not shift appreciably with change of incident proton energy. The $(p,\alpha)$ excitation functions are smoothly varying and are quite similar for various targets studied.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.
[1] C. B. Fulmer and B. L. Cohen, Bull. Am. Phys. Soc. **3**, 56 (1958); Phys. Rev. (to be published).

**C9. Scattering of 43-Mev $\alpha$ Particles by Nuclei.*** B. ZEIDMAN AND J. L. YNTEMA, *Argonne National Laboratory.*—The absolute differential cross sections for the elastic scattering of 43-Mev $\alpha$ particles by Zn, Rh, Ag, and Au has been measured over the angular range 10° to 70°. The work was done with the Argonne 60-in. scattering chamber. Two NaI(Tl) crystals, 0.003 in. and 0.030 in. thick, respectively, were used for the detection and particle identification. The angular resolution of the detector was 0.5°. The errors in the absolute differential cross section vary from 2% to 7%. The data indicate that the correction applied by Cheston and Glassgold[1] to the 40-Mev data of Eisberg, Igo, and Wegner[2] for Ag is approximately correct. Inelastic groups were observed in the $\alpha$-particle spectrum of Al at 3, 5, and 7 Mev, in V and Zn at 3 Mev and in Rh and Ag at about 2.5 Mev. The angular distributions of the inelastic groups in Al, Zn, Rh, and Ag show a pronounced structure.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] W. B. Cheston and A. E. Glassgold, Phys. Rev. **106**, 1215 (1957).
[2] Eisberg, Igo, and Wegner, Phys. Rev. **100**, 1309 (1956).

**C10. Angular Distributions and Yields of Conversion Electrons following Coulomb Excitation.*** E. M. BERNSTEIN, *University of Wisconsin.*—A magnetic $\beta$-ray spectrometer capable of measuring the angular distribution of conversion lines following Coulomb Excitation has been constructed. Preliminary angular distribution measurements of $K$ conversion lines of the following transitions have been made: Ta$^{181}$, 137 kev; Au$^{197}$, 279 kev and 550 kev. The results are consistent with the known spins and multipolarities involved. Conversion lines from three transitions (615, 740, and 790 kev) follwing Coulomb excitation of Th$^{232}$ have been measured. A comparison of the conversion electron yields with the gamma-ray measurements[1] of McGowan and Stelson lead to the following multipolarity assignments: 615, $E2$; 740, $E2+E0$; 790, $E2$. The electric monopole transition probability for the 740-kev,

$2^+ \rightarrow 2^+$ transition in terms of the strength parameter $\rho$ defined[3] by Church and Weneser is $\rho \approx 1/13$. The Th results are in agreement with a previous measurement.[3]

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
[1] F. K. McGowan and P. H. Stelson, Bull. Am. Phys. Soc. Ser. II, 2, 207 (1957), and private communication.
[2] E. L. Church and J. Weneser, Phys. Rev. 103, 1035 (1956).
[3] E. M. Bernstein and S. Buccino (unpublished).

**C11. Isomeric Cross Section Ratios and Angular Momentum Transfer for Nuclear Reactions Producing $Hg^{197}$ and $Hg^{197m}$.*** R. VANDENBOSCH, W. J. RAMLER, AND J. R. HUIZENGA, *Argonne National Laboratory.*—The cross sections of the isomers of $Hg^{197}$ ($I = 1/2$ and $13/2$) produced by the $Au^{197}(d,2n)$ and $Au^{197}(p,n)$ reactions were measured as a function of projectile energy. Deuterons of 21.5-Mev and protons of 10.7-Mev energy were degraded by aluminum absorbers to the desired energies. The isomeric cross section ratio for the thermal-neutron activation of $Hg^{196}$ was found to be $\sigma(13/2)/\sigma(1/2) = 0.044$, in agreement with the isomeric ratio rule for slow neutron capture.[1] By utilizing the transmission coefficients of Feshbach, Shapiro, and Weisskopf,[2] the distribution in angular momentum was calculated for the compound system formed at each of several bombarding energies, taking into account the spin of the target nucleus. From an analysis of the above angular momemtum distributions in conjunction with the experimental cross section ratios, a correlation is obtained between isomeric cross section ratios and discrete values of angular momentum. With this correlation obtained from reactions described by compound nucleus formation it is possible to interpret isomeric cross section ratios measured for reactions which may proceed by direct interaction mechanisms.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] E. Der Mateosian and M. Goldhaber, Phys. Rev. 108, 766 (1957).
[2] Feshbach, Shapiro, and Weisskopf, NDA Report 15B-5, 1953.

**C12. Deuteron Photodisintegration in the Region from 400 to 900 Mev.*** R. GOMEZ, H. MYERS, AND A. V. TOLLESTRUP, *California Institute of Technology.*—The differential cross section for the process $\gamma + D \; P + N$ at photon energies between 400 and 900 Mev is being measured at the C.I.T. Synchrotron Laboratory. The experiment is done by counting the protons from a liquid deuterioum target with a six counter telescope. It is possible to fix the energy and angle of the proton in such a way that no protons which originate in the deuterium from processes other than that of elastic photodisintegration are observed. Preliminary measurements made at 90 deg in the laboratory indicate that the cross section decreases from 1.6 $\mu$barns/sterad at a laboratory photon energy of 400 Mev to less than 0.05 $\mu$barns/sterad at 900 Mev. The existence of a resonance, corresponding to that observed in meson photoproduction[1,2] at 700 Mev, will be ascertained.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] F. P. Dixon and R. L. Walker, Phys. Rev. Letters 1, 142 (1958).
[2] R. R. Wilson (private communication).

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## WEDNESDAY MORNING AT 10:30

## New Orleans Room

## (W. A. NIERENBERG presiding)

### *Hyperfine Structure: Nuclear Magnetic Resonance*

**CA1. Theory of the Stark Effect on the hfs of the Cs Atom.** M. MIZUSHIMA,* *National Bureau of Standards, Boulder Laboratories.*—Haun and Zacharias[1] observed the Stark effect of the $(F=3, m_f=0) \rightarrow (F=4, m_f=0)$ transition of the Cs atom in its ground state and obtained $\Delta\nu'_{exp} = -2.29 \times 10^{-6} E^2$ cps, where $E$ is in volts/cm. The second-order perturbation theory they applied gave only about one-third of this observed value. It is pointed out that the third-order terms are important in this case and a reasonable estimation gives $-1.75 \times 10^{-6} E^2$ cps which agrees with the observed data.

* Permanent address: University of Colorado.
[1] R. D. Haun, Jr., and J. R. Zacharias, Phys. Rev. 107, 107 (1957).

**CA2. Level Inversion in the Hyperfine Structure of Gallium-72.*** L. J. KIEFFER, W. J. CHILDS, AND L. S. GOODMAN, *Argonne National Laboratory.*—The hyperfine structure of the $^2P_{\frac{3}{2}}$ atomic state of gallium-72 has been investigated by atomic beam methods for radioactive nuclei.[1] The spin of this nucleus has previously been reported as 3.[2] Resonances have been observed at several values of the field. From the resonances thus far observed the level sequence and approximate level spacings can be determined. The level sequence at zero field for a positive magnetic moment, in order of decreasing energy, is $F=7/2$, $5/2$, $9/2$, $3/2$. Consistent with this, three distinct field-dependent "flop in" resonances have been observed at a single setting of the homogeneous field. The values of the interaction constants[3] are $|a| = 6.177 \pm 0.53$ Mc/sec and $b/a = -31.26 \pm 0.14$. The errors quoted represent the experimental uncertainties in the resonances observed. From the interaction constants and data[4] on gallium-71 the following approximate moments can be calculated $|\mu| = 0.130 \pm 0.001$ n.m. and $|Q| = 0.72 \pm 0.07$ barn.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] L. S. Goodman and S. Wexler, Phys. Rev. 99, 192 (1955).
[2] L. S. Goodman and W. J. Childs, Bull. Am. Phys. Soc. Ser. II, 3, 21 (1958).
[3] N. F. Ramsey, *Molecular Beams* (Oxford University Press, London, 1956), p. 272.
[4] See reference 3, p. 174.

**CA3. Hyperfine Structure in the Metastable Triplet State of $He^3$.*** J. A. WHITE, C. W. DRAKE, AND V. W. HUGHES, *Yale University.*—The hyperfine structure of the $2\,^3S_1$ state of the $He^3$ atom has been redetermined by the atomic beam magnetic resonance method. Earlier measurements[1] had indicated that the frequency corresponding to the $\Delta m_F = 0$ transition between the $(F, m_F) = (\frac{3}{2}, -\frac{1}{2})$ and the $(F, m_F) = (\frac{1}{2}, -\frac{1}{2})$ levels should be a minimum, and hence only quadratically field dependent, at a magnetic field of about 800 gauss. This minimum frequency was located and accurately measured. The hyperfine splitting, which according to the Breit-Rabi formula is exactly $3/(2\sqrt{2})$ times the minimum frequency, is 6739.7022 Mc/sec with an estimated uncertainty of 1 part in $10^7$. The present value is in agreement with the earlier value[1] which had an uncertainty of 7 parts in $10^6$.

* This research supported in part by the National Science Foundation, the Air Force Office of Scientific Research, and the Office of Naval Research.
[1] G. Weinreich and V. W. Hughes, Phys. Rev. 95, 1451 (1954).

**CA4. Nuclear Spins of $Br^{80m}$ and $Br^{80}$.*** E. LIPWORTH, H. L. GARVIN, AND T. M. GREEN, *University of California, Berkeley.*—The nuclear spins of 4.5 hr $Br^{80m}$ and 18 min $Br^{80}$ have been determined by the method of atomic beams. The active isotopes are prepared by the reaction $Br^{79}[n,\gamma]Br^{80m}$ on KBr powder. The bromine is liberated chemically and passed through an rf discharge tube to produce the atomic beam. The beam is collected upon silver-coated buttons which are counted in methane beta counters. Both isotopes are detected by observing the decay beta particle from $Br^{80}$. As $Br^{80m}$ and $Br^{80}$ are connected only by an isomeric transition, the resonance buttons exposed for $Br^{80}$ exhibit a pure decay, but buttons exposed for $Br^{80m}$ must await the population of the ground state of $Br^{80}$ before they can be detected. This results in a composite decay of the $Br^{80m}$ resonance button. Resonances have been observed at several different magnetic fields in both isotopes. All resonances observed are consistent with assignment for 5 for the nuclear spin of $Br^{80m}$ and of 1 for $Br^{80}$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**CA5. Overhauser Type Experiments in NMR Spectra.** G. A. WILLIAMS AND F. BLOCH, *Stanford University.*—The partial or total saturation of a resonance line causes a deviation from the equilibrium populations not only in the pair of levels directly involved, but, through relaxation transitions, also in other energy levels of the spin system, and hence, a change $\Delta I$ in the signal intensity of any other resonance line. Application of a strong rf field at the frequency of each of the $n$-resonance lines in a spectrum yields thus a set of $n$-$1$ relative intensity changes $\Delta I/I$ for the remaining resonance lines, observed by a weak rf field at their corresponding frequencies, or $n$-$2$ values for their ratios. The $n(n$-$2)$ data thus obtained are uniquely related to the ratios of the transition probabilities, and they can be used for obtaining information about the latter and, hence, about the underlying relaxation mechanism. The method has been applied to the system of two nonequivalent protons in 2-bromo-5-chlorothiophene. Sizable intensity changes, both positive and negative, have been observed, depending on which of the four lines is strongly irradiated and which is observed, but the present data and their accuracy are not yet sufficient to draw quantitative conclusions.

**CA6. Splitting in Solid $Cl_2$ Quadrupole Resonance.*** LANGDON CRANE AND ROY ANDERSON, *University of Maryland,* AND H. G. ROBINSON, *Yale University.*—Two nuclear quadrupole resonances have been resolved in solid polycrystalline $Cl_2$ at 77°K. The samples were prepared by condensing chlorine gas at dry ice temperature and subsequently freezing in liquid air. The $Cl^{35}$ splitting is 3.3 kc; $Cl^{37}$ splitting is 2.7 kc. Both line widths appear to be less than 4 kc. Intensity ratios of the $Cl^{35}$ and $Cl^{37}$ doublets are, respectively, $\approx 3.6{:}1$ and $\approx 3{:}1$. In both cases the stronger component of the doublet is lower in frequency. Splittings were first observed with a super-regenerative spectrometer. However, because of ambiguity in line shape with this type of detection, a recording regenerative detector was used to obtain the above data. Structured lines have also been reported by other workers[1,2] in solid $Br_2$ and $I_2$. In these molecules the effect has been attributed to an electron-coupled nuclear dipole-dipole interaction. Such an interaction in $Cl_2$ is expected to be orders of magnitude smaller than the observed splitting. A discussion of this and other possible explanations will be given.

* This work supported by the National Security Agency.
[1] Kojima *et al.*, J. Phys. Soc. Japan 12, 1225 (1957).
[2] G. D. Watkins and R. M. Walker, Bull. Am. Phys. Soc. Ser. II, 1, 11 (1956).

**CA7. Proton Resonance Spectra of a Number of Amino Acids.*** L. DWIGHT FARRINGER, L. CARLTON BROWN, AND DUDLEY WILLIAMS. *The Ohio State University.*—The proton resonance spectra of solutions of fourteen of the more common amino acids in $D_2O$ and in pure $H_2SO_4$ have been studied. The concentrations of the solutions in $D_2O$ were varied for some of the compounds in order to study the shift in resonances with change in concentration. The compounds studied were glycine, *DL*-alanine, cysteine·HCl, *L*-arginine·HCl, *DL*-lysine·HCl, *L*-lysine·HCl, *L*-lysine·2HCl, *DL*-asparagine ·$H_2O$, *DL*-*B*-phenylalanine, *DL*-serine, *DL*-methionine, *L*-leucine, and *DL*-isoleucine. Molal concentrations from 0.03 to 2.4 were studied. In general, the proton resonances shift to lower fields with increased concentrations. Quantative results will be displayed and discussed.

* This work was supported in part by the Office of Naval Research.

**CA8. Nuclear Magnetic Resonance Study of $B_2O_3 \cdot xH_2O$ Materials.** A. H. SILVER, *Ford Motor Company.*—In order to determine the effect of water content on the structure of glass, the series $B_2O_3 \cdot xH_2O$ has been studied with NMR techniques. Previous studies of "dry" glass, $B_2O_3$, showed that the structural units are $BO_3$ triangles joined through the common oxygen atoms. In the orthoboric acid, $B_2O_3 \cdot 3H_2O$, the $BO_3$ triangular units are joined by hydrogen bonding. The measured boron quadrupole coupling constant is the same in both materials. In orthorhombic metaboric acid, $B_2O_3 \cdot H_2O$, the $BO_3$ triangles share some oxygen atoms directly, the remaining oxygen atoms being hydrogen bonded. Again the boron quadrupole coupling is large and in agreement with the value in $B_2O_3$ glass and $B_2O_3 \cdot 3H_2O$. The spectrum from a "wet" glass with approximate composition $B_2O_3 \cdot \frac{1}{2}H_2O$ shows that the quadrupole interaction of most boron atoms is the same as in dry glass, implying the same basic $BO_3$ units in agreement with recent x-ray evidence.[1] However, for some of the boron atoms the quadrupole interaction is greatly reduced indicating a change in coordination from $BO_3$ to $BO_4$. The formation of some $BO_4$ tetrahedra is not unreasonable since both $BO_3$ and $BO_4$ units exist in the monoclinic form of metaboric acid.

[1] M. E. Milberg (to be published).

**CA9. Optical Polarization of Atomic Nitrogen.*** L. WILMER ANDERSON, FRANCIS M. PIPKIN, AND JAMES C. BAIRD, JR., *Harvard University.*—The low field Zeeman transitions of atomic nitrogen have been detected by an experiment in which nitrogen atoms were oriented by spin-exchange collisions with optically polarized sodium. The apparatus was similar to that used in a previous experiment on atomic hydrogen.[1] The circularly polarized light transmitted by a Pyrex bulb containing a mixture of argon, nitrogen, and vacuum distilled sodium was monitored with a photocell. An electrodeless discharge was used to dissociate the nitrogen molecules into atoms. The atomic state of nitrogen is $^4S_{\frac{3}{2}}$ and the nuclear spin is 1 for $N^{14}$. Thus, the atom has a total angular momentum $F$ of 5/2, 3/2, and 1/2. For low magnetic fields, where the linear approximation for the Zeeman energy levels is valid, the $g$ factors for these states are 6/5, 22/15, and 10/3, respectively. Zeeman transitions have been observed for magnetic fields of 1 and 1.5 gauss for the $F=5/2$ and $F=3/2$ states. At these low fields the line is broadened owing to the breakdown of the linear approximation for the Zeeman energy levels. This is consistent with the small hyperfine splitting for nitrogen reported by Heald and Beringer.

* Research supported in part by a grant from The Research Corporation.
[1] Anderson, Pipkin, and Baird. Phys. Rev. Letters 1, 229 (1958).

**CA10. Determination of the Dipole Moment and Isotope Shift of Radioactive $Hg^{197}$ by "Double Resonance."** ADRIAN C. MELISSINOS,* *MIT* (sponsored by Francis Bitter).—Paramagnetic resonance was established between $m$ sublevels ($\Delta m = \pm 1, \Delta F = 0$) of the $^3P_1$ state of radioactive $Hg^{197}$ a

3000 Mc. From these data the nuclear interaction constant $A$ is found to be 513.5±1 mK, and barring hfs anomalies it leads to a ratio of moments $\mu_{197}/\mu_{199}=A_{197}/A_{199}=1.045$; further, the nuclear spin of $Hg^{197}$ was ascertained to be $\frac{1}{2}$. The double resonance was combined with magneto-optic scanning[1] to give the isotope shift of $Hg^{197}$, which was found to be in the 2537 A line +91±5 mK from $Hg^{198}$. The radioactive mercury was produced by the $Au^{197}(d,2n)Hg^{197}$ reaction and used in vapor form. Satisfactory signals were obtained with as few as $3\times10^{13}$ atoms.

* Present address: University of Rochester.
[1] Sagalyn, Melissinos, and Bitter, Phys. Rev. 109, 375 (1958).

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## WEDNESDAY MORNING AT 9:45

## Empire Room

## (FELIX VILLARS presiding)

### *Theoretical Physics I: Largely Atomic Theory*

**D1. Two-Dimensional Lattice Sums in a Three-Dimensional Space.*** PHILIP PARZEN, *Parzen Associates.*—Many problems in solid-state and electromagnetic theory require the evaluation of the field at any point in space due to a two-dimensional periodic lattice of point sources with strengths differing by a phase factor. While the far field is easily obtained, the fields at near and intermediate points are relatively more complicated to compute. This paper presents a method of obtaining these fields in the form of rapidly convergent series. The basic idea is to expand the field in spherical harmonics with coefficients given by rapidly convergent series. Simple symmetry considerations induced by the symmetry operations of the two-dimensional lattice show that many coefficients vanish and simplify the computation. The summation is accomplished by an extension of Ewald's method of the field due to three-dimensional lattice sums to this case. Explicit calculations for a square lattice will be given.

* This work was done at the Polytechnic Institute of Brooklyn.

**D2. Nuclear Effects in Electron Spin Resonance.*** DANIEL KIVELSON, *University of California at Los Angeles.*—The relaxation times $T_1$ and line widths $T_2^{-1}$ arising from intramolecular nuclear-electronic dipolar interactions have been studied within the framework of the theory of Kubo and Tomita.[1] Both $T_1$ and $T_2$ are shown to be functions of the nuclear quantum numbers; and, furthermore, even for extreme motional narrowing $T_1$ is not quite equal to $T_2$ for each hyperfine line. The central lines are narrower but saturate more readily than do the outer ones. Calculations indicate that the intramolecular nuclear-electronic dipolar interactions contribute significantly to the relaxation mechanisms in $ON(SO_3)_2^=$, and somewhat less in aromatic free radicals.

* Partially supported by a National Science Foundation Grant.
[1] R. Kubo and K. Tomita, J. Phys. Soc. 9, 888 (1954).

**D3. Positron Annihilation in Metals.*** S. KAHANA, *McGill University* (sponsored by E. L. Lomon).—An attempt is made to explain the rather short annihilation lifetimes for positrons in metals in terms of two-body correlations between positron and individual electrons. The many-body correlations of the electron medium are included only through the Pauli principle and a screening of the positron-electron Coulomb force. In this sense the calculation carried out here is similar to that of Ferrell,[1] but perturbation theory is avoided. A Bethe-Goldstone like equation is set up using the unscreened Coulomb potential, and solved in as exact a manner as possible. The results yield at zero relative energy too short lifetimes but displaying a constancy over a considerable range of Fermi energies. The variation of lifetime with relative electron-positron energy is in the wrong direction. Considerations of the screening of electron-positron force in the metal indicate that the lifetime will be decreased and the variation with Fermi energy smoothed out even more.

* This work was begun under the auspices of the Atomic Energy of Canada.
[1] R. A. Ferrell, Revs. Modern Phys. 28, 308 (1956).

**D4. The Variation of Slater Parameters with Term Structure.** R. E. TREES, *National Bureau of Standards.*—The Slater theory is often applied by assuming that similarly defined radial integrals are equal in all terms of a given configuration. Recently, empirical corrections have been added to the theory to take account of the inaccuracy of this approximation and other sources of error. In the $d^r$ configuration there are two parameters associated with these corrections (i.e., the $\alpha L(L+1)$ and $\beta Q$ corrections). The approximation is a first-order effect and its contributions to the corrections can probably be evaluated on a nonempirical basis. However, the present calculation was an effort to estimate orders of magnitude with a simple model. Energies of the five terms of the $3d^2$ configuration of a two-electron atom were determined by regarding the effective charge of the hydrogenic one-electron wave functions as a variation parameter. The calculated energies were then treated as observed data to determine effective Slater parameters and empirical corrections. $\alpha$ had a negligibly small value that would not be observable ($\alpha=-1$ cm$^{-1}$). This seems to be an accident resulting from the use of a Coulomb field, as other effects had observable magnitudes. The value of $\beta Q$ was $-300$ cm$^{-1}$. Values of $\alpha$ and $\beta$ are rigorously independent of atomic number for this model, in agreement with the fact that observed values of $\alpha$ are relatively constant in the third long period.

**D5. Variational Calculations of Energy and Fine Structure for the $2^3P$ State of Helium.** J. TRAUB* AND H. M. FOLEY.—Using an eighteen parameter Hylleraas-type wave function containing only positive powers, a calculation has been carried out for the $2^3P$ state of helium by the Ritz variational principle. Breit's reduction was used to convert the problem from six to three variables. The energy was minimized by the approximate solution of an eigenvalue problem. With this wave function the fine structure splitting was calculated. Numerical work was carried out on an IBM 650 computer. Numerical results and comparison with experiment will be presented.

* Watson Laboratory Fellowship, IBM.

**D6. Effect of an Electric Dipole Moment of the Proton on the Energy Levels of the Hydrogen Atom.*** R. M. STERNHEIMER, *Brookhaven National Laboratory.*—The perturbations of the energy levels of the hydrogen atom by a possible electric

dipole moment of the proton $d$ have been obtained. The inhomogeneous equation for the first-order perturbation of the wave functions[1] was solved analytically. The shifts of the energy levels are of the second order in $d$. In particular, there results a decrease of the Lamb shift between the $2S_{\frac{1}{2}}$ and $2P_{\frac{1}{2}}$ levels. By equating this decrease to the maximum allowed by the approximate agreement between the experimental and theoretical values of the Lamb shift, it is concluded that the electric dipole moment of the proton $d$ must be less than $1.3\times10^{-13}$ cm times the charge of the electron. A nonvanishing $d$ would indicate a violation of time reversal invariance. Calculations have also been carried out for the shifts of the energy levels of deuterium produced by a possible electric dipole moment of the deuteron.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] R. M. Sternheimer, Phys. Rev. **84**, 244 (1951); **96**, 951 (1954).

**D7. Dispersive Effects in Electron-Nucleus Problems.*** N. A. KRALL AND E. E. SALPETER, *Cornell University*.—The nonstatic nature of the real nucleus affects both electron scattering and the energy levels of bound electrons. In scattering these dispersive effects, which consider excited intermediate nuclear states, are accurately calculated in second Born approximation. Various schemes are used in different regions of intermediate electron momenta to enable the sum over nuclear intermediate states to be done. The calculation of electron-deuteron scattering is made at seven combinations of energy and angle, from $q=1$ at $p_0=188$ Mev/$c$ to $q=2.6$ at $p_0=500$ Mev/$c$. A change in $\langle r^3\rangle_{\text{deuteron}}$ of about $-0.04$ (fermi)$^3$ is obtained. In bound $s$ sta.es, the energy level shift due to nuclear size and structure, including dispersive effects, is recalculated through second-order perturbation theory. The shift for the $2S_{\frac{1}{2}}$ level in deuterium is $0.87_8$ Mc, including the proton size. The scattering and bound state problems are also solved, in less detail, for heavier nuclei.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**D8. Multiplet Strengths and Sum Rules.** F. ROHRLICH, *National Bureau of Standards Boulder Laboratories and The Johns Hopkins University*.—General formulas were derived for the line strength and the multiplet strength factors of the absolute electric dipole transition strengths in atomic spectra. Multiple occurring terms are separated by means of fractional parentage coefficients. These formulas replace all previous tables of line strengths and multiplet strengths, especially the the extensive tables by Goldberg.[1] A tabulation now becomes unnecessary, since Racah coefficients and Wigner 9$j$ coefficients have been tabulated. Many errors were found in previous tables. The formulas can easily be summed over various quantum numbers producing many new sum rules, as well as the well-known sum rules. The application of these results to the analysis of observed line strengths will be discussed.

[1] L. Goldberg, Astrophys. J. **82**, 1 (1935).

**D9. Negative Atomic Ions.** H. JOHNSON, *National Bureau of Standards Boulder Laboratories*, AND F. ROHRLICH, *The Johns Hopkins University*.—The ionization potentials (electron affinities) of negative atomic ions are computed by extrapolation of the ionization potentials of their respective iso-electronic sequences. Previous work using quadratic extrapolation is unsatisfactory for reasons which will be discussed. Our method is based on a five parameter extrapolation formula which can be justified on physical grounds and in which some of the parameters have direct physical meaning and thus provide a check on the procedure. The results agree within experimental error with all negative ions of the first two short periods except $S^-$. A bound $N^-$ is predicted and bound excited states in $B^-$, $Al^-$, and $P^-$ are to be expected.

**D10. Bremsstrahlung and the Photoelectric Effect as Inverse Processes.*** K. W. MCVOY, *Brandeis University*, AND U. FANO, *National Bureau of Standards*.—The bremsstrahlung matrix element at the short wavelength limit of the spectrum is calculated to lowest order in $\alpha=Z/137$, for an unscreened Coulomb field. The result, valid for relativistic incoming electrons, is shown to be exactly $(\alpha^2mc^2)^{-\frac{1}{2}}$ times the complex conjugate of Sauter's relativistic matrix element for the $K$-shell photoelectric effect. These matrix elements are the leading terms in an expansion of the exact matrix elements in powers of $\alpha$, and they are found to be derivable from the first two terms of the expansions in powers of $\alpha$ of the electron wave functions. In this sense their structure is completely analogous to that of the Bethe-Heitler bremsstrahlung matrix element. This simple relation between the matrix elements derives from an approximate equality (through first order in $\alpha$) between the Coulomb wave functions for bound and zero-momentum continuum states, which can be understood as due to the neglect of the Coulomb binding energy, a second-order quantity in $\alpha$.

* Work performed under the auspices of the U. S. Atomic Energy Commission and the Office of Naval Research.

**D11. Interference of Orbital and Spin Currents in Bremsstrahlung and Photoeffect.*** U. FANO, *National Bureau of Standards*, AND K. W. MCVOY, *Brandeis University*.—The matrix elements of the Born approximation theory of bremsstrahlung can be resolved into contributions classified according to whether the radiation arises from orbital or from spin currents and on the basis of additional spin effects which result from electron motion before and after the interaction. Observable features of angular distribution, x-ray polarization, and spin orientation can be interpreted as effects of interference between separate contributions. The results are applicable to corresponding features of the photoeffect.

* Supported, in part, by the Office of Naval Research.

**D12. Atomic High-Energy Photoeffect.** F. NAGASAKA, *Catholic University of Nagoya, Japan*, AND EUGENE GUTH, *Oak Ridge National Laboratory*.—The atomic high-energy $K$-shell photoeffect has been calculated, using exact Dirac wave functions for the bound state and Sommerfeld-Maue wave functions for the outgoing electron. Both angular distributions and total cross sections were obtained; the latter are consistently smaller than those obtained previously[1] and are in correspondingly better agreement with experiment. The angular distribution gives a nonvanishing intensity in the direction of the primary gamma ray, in agreement with experiment,[2] while Sauter's approximation (first power in $\alpha Z/\beta$), which is *not* the Born approximation, gave vanishing intensity. The reason: relativistically the matrix elements for the $s_{\frac{1}{2}}-p_{\frac{1}{2}}$ and $s_{\frac{1}{2}}-p_{\frac{3}{2}}$ tranisitions are different (but nonrelativistically they are equal). The effect of binding both for the ground state and the outgoing wave function was investigated in detail. This work is part of a systematic study of radioactive processes using Sommerfeld-Maue wave functions (also in the approximation of Olsen, *et al.*[3]) Work has been finished on gamma production of slow pairs (resolving discrepancy between Rose and Uhlenbeck[4] and Nishina *et al.*[5]). Bremsstrahlung, particularly the short wave limit, is being studied.

[1] Harvey Hall, Revs. Modern Phys. **8**, 358 (1936).
[2] Hedgran and Hultberg, Arkiv Fysik **9**, 245 (1955).
[3] Olsen, Maximon, and Wergeland, Phys. Rev. **106**, 27 (1957).
[4] M. E. Rose and G. E. Uhlenbeck, Phys. Rev. **48**, 211 (1935).
[5] Nishina, Tomonaga, and Sakata, Sci. Papers Inst. Phys. Chem. Research (Tokyo) Suppl., **R24**, (1934).

**D13. Distribution of Recoil Momenta in Triplet Production.*** KIU S. SUH AND H. A. BETHE, *Cornell University*.—The production of an electron pair by a very energetic gamma ray

in the field of an electron (triplet production) is studied, following the work of Borsellino.[1] The distribution of recoil momenta $q$ is calculated for $q$ of order unity (in units of $\hbar=m=c=1$) and is compared with the recoil distribution in the case of pair production in the field of a nucleus. It is seen that the two distributions agree if appropriate variables are used. The total cross sections, therefore, also agree in the high-energy limit, as previously stated by Borsellino. When the recoil electron is originally bound in an atom, our result agrees with the Wheeler-Lamb value.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] A. Borsellino, Nuovo cimento 4, 12 (1947).

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WEDNESDAY AFTERNOON AT 2:00

Empire Room

(G. E. UHLENBECK presiding)

## *Theoretical Physics II: Statistical Theory, General Relativity*

**E1. Pair Distribution Functions for Interacting Particles.** R. U. AYRES, *University of Maryland* (sponsored by Ralph Myers).—A method is proposed for calculating the pair-distribution function for a Bose or Fermi gas from the scattering wave functions. The approximation involved seems to be roughly equivalent to other treatments which take account of 2-body correlations. The energy of the many-body system can be calculated to first order in terms of 2-body phase-shifts, and results for a hard-sphere gas and a Lennard-Jones potential are consistent with those found by Yang and Huang[1] and Abe.[2] It is thought that the use of phase shifts may be especially useful in the nuclear problem where the exact shape of the potentials are unknown.

[1] P. N. Yang and K. Huang, Phys. Rev. 105, 767 (1957).
[2] R. Abe, Progr. Theoret. Phys. 19, 713 (1958).

**E2. Correlation Energy and Pair Distribution Function for a Degenerate Electron Gas.*** ARNOLD J. GLICK AND RICHARD A. FERRELL, *University of Maryland*.—The interaction energy of an electron gas can be expressed in terms of the Fourier transform $P(k)$ of the pair distribution function $g(r)$. Using first-order perturbation theory to calculate $P(k)$ leads to the well-known logarithmic divergence in the correlation energy. The calculation can be improved[1] by expressing $P(k)$ in terms of the dynamic dielectric constant for the electron gas. Going to the limit of high electron density leads to the Gell-Mann-Brueckner[2] result. The advantage of working explicitly with the pair distribution function is that there exist general criteria for checking the validity of approximate calculations for the case of arbitrary density. $P(k)$ and $g(r)$ must both satisfy positive definiteness criteria since $P(k)$ is related to the cross section for scattering fast-charged particles and $g(r)$ is a probability density. $g(r)$ is further restricted in that the value of $\int g(r)d^3r$ is assigned *a priori*.

* Investigation supported in part by the U. S. Atomic Energy Commission and by the Office of Naval Research.
[1] P. Nozières and D. Pines, Nuovo cimento 9, 470 (1958).
[2] M. Gell-Mann and K. A. Brueckner, Phys. Rev. 106, 364 (1957).

**E3. Derivation of the Debye-Hückel Plasma Energy from Perturbation Theory.** HUGH E. DEWITT, *University of California, Livermore*.—The potential energy of a quantum mechanical high temperature fully ionized gas with Boltzmann statistics assumed has been derived by the technique of summing the perturbation series in a manner similar to the Gell-Mann and Brueckner treatment of the zero temperature electron gas.[1] As in the zero temperature case the terms of the perturbation series are of alternating sign and the $n$th term corresponding to the Coulomb interaction between $n$ particles has a divergence of order $2n$ for small momentum transfer. The summation of this divergent series gives a finite result which may be expanded in powers of $\hbar$; the leading term is the classical Debye-Hückel plasma energy. In this derivation only the Feynman diagrams with the interactions taken in cyclic order are considered. These diagrams correspond to the ring integrals of the Mayer cluster integral method.[2] The contribution of the noncyclic diagrams and of the exchange diagrams when Fermi statistics are assumed will also be discussed.

[1] M. Gell-Mann and K. A. Brueckner, Phys. Rev. 106, 364 (1957).
[2] E. W. Montroll and J. C. Ward, Phys. Fluids 1, 55 (1958).

**E4. Quantum Statistical Pair Distribution Function.** S. FUJITA, A. ISIHARA, AND E. W. MONTROLL, *University of Maryland*.—Using the idea of "torons" introduced by Montroll and Ward,[1] it is shown that the pair distribution function in the grand canonical ensemble is expressed in terms of propagators corresponding to the normal and exchange scattering of two "torons" in position-temperature space. The "toron" is a mathematical entity which circulates around the positron-temperature torus and in terms of which the quantum-statistical effect is conveniently expressed. Since the momentum representation of the propagators of torons is found to take the same expression for the classical and quantum statistical cases, there exists a simple transformation which enables us to write down the quantum statistical counterpart from the Boltzmann statistical propagators. Assuming small coupling constants, the diagrams representative of "toron" scattering are analyzed by using the same methods in quantum field theory. Explicit calculations are made for the pair distribution function of an electron gas at low and high temperatures.

[1] E. W. Montroll and J. C. Ward, Phys. Fluids 1, 55 (1958).

**E5. Asymptotic Value of the Pair Distribution Function at a Wall.*** J. L. LEBOWITZ, *Stevens Institute of Technology*.—It is shown that the conditional probability density $p^w(\mathbf{r}_2/\mathbf{r}_1)$ finding a particle in the neighborhood of a point $\mathbf{r}_2$ in the interior of a fluid when it is known that there is a particle at $\mathbf{r}_1$ in contact with the rigid walls of the container, approaches the value $\rho-(\rho^2kT/pN)$ for $\mathbf{r}_2$ far from the wall. Here $\rho$ is the number density at $\mathbf{r}_2$, $p$ the pressure, and $N$ the total number of particles in the box. This relation is to be contrasted with the well-known Orenstein-Zernike expression for the asymptotic value of $p(\mathbf{r}_2/\mathbf{r}_1)=p(|\mathbf{r}_2-\mathbf{r}_1|)$ when both $\mathbf{r}_1$ and $\mathbf{r}_2$ are in the interior of the fluid,

$$\lim_{r_{12}\to\infty} p(r_{12})=\rho-\rho^2(kT\chi_T/N),$$

where $\chi_T$ is the isothermal compressibility. The derivation of the asymptotic value of $p^w(\mathbf{r}_2/\mathbf{r}_1)$ is based on the virial theorem for the fluctuations in the total momentum in an equilibrium ensemble.[1] Since it appears that these fluctuations behave

classically even for liquid helium II our considerations apply also to quantum systems.

* Supported by the Office of Scientific Research.
[1] J. L. Lebowitz, Phys. Rev. **109**, 1464 (1958).

**E6. Equation of State of Hard Sphere Fluids.** H. REISS AND H. L. FRISCH, *Bell Telephone Laboratories*, AND J. L. LEBOWITZ,* *Stevens Institute of Technology*.—A set of relations has been discovered which determines to within a high degree of approximation the value of the radial distribution function for hard spheres in contact. In the case of hard spheres this one value, $g$, of the radial distribution function suffices to determine the equation of state and so the aforementioned relations yield the equation of state to the same degree of approximation. The principal relation is obtained by computing the pressure in two different ways and equating the results. First, the pressure is computed using the virial theorem leading to a relation containing $g$. Alternatively, the pressure can be computed in terms of an integral involving the radial distribution function $G$ at contact for a normal hard sphere molecule around a hard sphere solute molecule of smaller size. The integral is over the radius $r$ of the solute as it passes from zero to the size of the other hard spheres.

* Supported by the Office of Scientific Research.

**E7. On a Model for Certain Computing Nets and its Relation to Statistical Mechanics.** MANFRED KOCHEN, *IBM Research Center*.—A precise analogy between a model for irreversible statistical mechanics[1] and a model for certain networks of probabilistic transducers (i.e., sequential circuits of relays connected in a circle) is investigated. Each of $N$ devices, connected in a circle, emits one of two signals in each of a discrete number of time intervals. The probability of the output signal presently emitted depends only on the output signals of its right and/or left neighbor at the preceding time step. It is shown that if the conditional probability of an output signal of at least one device, given the preceding output of its right neighbor, is not 0 or 1, then, eventually, the probability of either output by any of the $N$ devices converges to $\frac{1}{2}$. A theorem specifying the rate at which this disorganization occurs is proved, and similar results for generalizations of the model are derived. Possible applications to the determination of reliability parameters in computing machines are discussed. This model is a special case of a general ergodic theorem for finite state, stationary Markov chains, and it extends the analogous model by Kac for statistical mechanics.

[1] M. Kac, Bull. classe sci. Acad. roy. Belg. **42**, 356–361 (1956).

**E8. Transverse Collective Coordinates in the Many-Body Problem.*** G. J. YEVICK, *Stevens Institute of Technology*, AND J. K. PERCUS, *N. Y. U. Institute of Mathematical Sciences*.—One knows that in the strong coupling limit (i.e., solid state) the collective coordinates for the many-body problem comprise $N$ longitudinal and $2N$ transverse modes. One can show that the symmetric collective coordinates $\Sigma_i \exp i\mathbf{k}\cdot\mathbf{x}_i$ correspond under certain restricted conditions to the longitudinal modes. The problem arises as to identifying the transverse symmetric collective modes (e.g., perhaps "rotons"). In order to determine the character of a postulated coordinate-dependent mode in an intermediate coupling domain, we take the extreme strong coupling limit, in which the concept of transversality is unique and meaningful. This is done for several physical classes of intermediate coupling modes, corresponding to multiple vortex field, dipole field, etc. Given any such field, we now have a method based upon the strong coupling limit for generating classically the transverse part of the field and thereby yielding the corresponding transverse collective coordinate. Intrinsically, velocity-independent transverse modes sample fine details of the particle configuration, unlike the longitudinal modes. By means of an appropriate perturbation theory, this sensitivity is diminished and a velocity dependence appears. Preliminary extension to the quantum mechanical problem of the high-energy spectrum of a Bose fluid will be presented.

* Supported in part by the Office of Naval Research.

**E9. Semiclassical Approach to the Many-Body Problem.*** J. K. PERCUS, *N. Y. U. Institute of Mathematical Sciences*, AND G. J. YEVICK, *Stevens Institute of Technology*.—In previous work, an investigation has been made of a classical perturbation method for the generation of angle-action variables in many-body systems. The problem of unlinked clusters was resolved and various closed form summations obtained. The diagrams which had to be analyzed were all of the form of "trees." This procedure has now been extended to quantum mechanics. Several novel features arise. In the most straightforward approach, Poisson brackets are replaced by higher order differential operators on phase space and trees give way to more general graphs. However, the WKB character of the resulting expansion is belied by the nonexistence of a "reasonable" limit as $\hbar$ tends to zero. The difficulty has been traced to the implicit use of a nonpositive definite (Wigner) probability in phase space. To overcome this limitation, a large class of positive definite probability distributions has been obtained which can serve as starting points for a more rational quantum mechanical perturbation theory. A sequence of approximations has been developed according to the degree of nonclassical behavior, corresponding to the number of trees which must be connected to form a complete graph.

* Supported in part by the Office of Naval Research.

**E10. Kinetic Equations for Relaxation Processes.*** P. M. MATHEWS, I. I. SHAPIRO, AND D. L. FALKOFF, *Brandeis University*.—We consider the relaxation of a system interacting via binary collisions with a reservoir whose distribution is time independent but does not necessarily correspond to that for thermal equilibrium. The state of the system at any time is specified by the occupation numbers for its quantum states. Using the generating function methods described by Moyal,[1] we have derived appropriate equations for the time-dependent probability distribution of the occupation numbers. These include the equations for the relaxation of the mean values of the occupation numbers obtained by Montroll and Shuler[2] for the case of a system of harmonic oscillators. Applications to the relaxation of interacting spins and phonons have also been considered.

* This research is supported by the Air Force Cambridge Research Center and the Office of Naval Research.
[1] J. E. Moyal, J. Roy. Stat. Soc. **B**, 150 (1949).
[2] E. Montroll and K. E. Shuler, J. Chem. Phys. **26**, 454 (1956).

**E11. Eliminating the Fourlegs from Gravity-Fermion Interaction Theory.** J. C. GARRISON AND F. J. BELINFANTE, *Purdue University*.—The gravitational Lagrangian may be written in terms of fourlegs (*Vierbeine*) $h_{(\alpha)^\mu}$. In absence of Fermion interactions obviously the six "Euler angles" $y$ which in each point indicate the chosen fourleg orientation represent "fake" coordinates,[1] and the "true" coordinates depend on $g_{\mu\nu}$ only. In Belinfante's "altered" theory,[1] the $S_{(\alpha)(\beta)}$ of the fourleg conditions then *depend throughout*[1] on the $p_y$ canonically conjugate to $y$. If Fermion interactions are present, canonized[1] variables $\bar{q}$ and $\bar{p}$ should be used. Now $\bar{p}_y$ will contain Fermion terms besides the $S_{(\alpha)(\beta)}$, and a canonical transformation must be found so that the transformed $\bar{p}_y'$ depend throughout on $S_{(\alpha)(\beta)}$ and vice versa. The canonical transformation will introduce new matter variables $\bar{\psi}'$, but will not affect the fourleg field itself, nor $g_{\mu\nu}$, so that the true gravitational variables remain functionals of $g_{\mu\nu}$. The fourleg constraints

$$p_{(\alpha)\mu}h_{(\beta)^\mu} - p_{(\beta)\mu}h_{(\alpha)^\mu} = -\tfrac{1}{4}\hbar c(-g)^{\frac{1}{2}}\bar{\psi}[\gamma^{(\alpha)}\gamma^{\mu}\gamma^{(\beta)} - \gamma^{(\beta)}\gamma^{\mu}\gamma^{(\alpha)}]\psi$$

may be satisfied for state vectors given in terms of $g_{\mu\nu}$ and true matter variables $q_{mi}$, even though $[p_{(\alpha)\mu}h_{(\beta)}{}^{\mu}-p_{(\beta)\mu}h_{(\alpha)}{}^{\mu}]$ vanishes for functions of $g_{\mu\nu}$ only, because $q_{mi}$ will contain $h_{(\alpha)}{}^{\mu}$ besides $\psi$ and $\bar{\psi}$.

[1] Belinfante, Caplan, and Kennedy, Revs. Modern Phys. **29**, 518 (1957).

**E12. Energy Flux of Gravitational Waves.*** JOHN BOARDMAN AND PETER G. BERGMANN, *Syracuse University.*—The rigorous cylindrically symmetric solution of the field equations of the general theory of relativity recently has been revised to show that these waves do carry energy.[1] No rigorous solution has yet been obtained for gravitational waves of spherical symmetry. However, the linear approximation to the field equations shows that energy travels outward from a radiating mass point quadrupole. This energy flux and the curvature tensor have been found for each of the four physically different possible types of symmetry of the quadrupole. A qualitative check of the validity of this approximation is made by comparison of the rigorous and linear approximation solutions of the field equations for cylindrical symmetry.

* Supported by Aeronautical Research Laboratory, WADC.
[1] L. Marder, Proc. Roy. Soc. (London) **A244**, 524 (1958); N. Rosen, Phys. Rev. **110**, 291 (1958).

**E13. Reduction of Secondary Constraints of General Relativity.** JAMES L. ANDERSON, *Stevens Institute of Technology.*—By making use of the coordinate condition, $g_{\mu 0}=-\delta_{\mu 0}$, it is possible to simplify the form of the secondary constraints of general relativity. Three of the secondary constraints take the form $\pi_{ij}{}^{ij}=0(i,j=1,2,3)$ where $\pi^{ij}$ is the momentum density conjugate to $g_{ij}$, and the bar denotes covariant derivative. The fourth constraint becomes $H=0$ where $H$ is the Hamiltonian density of the theory. Although very much simplified, the constraints are still too complicated to allow an easy construction of the true observables of the theory so that further reduction is required. To effect a further reduction, we solve the first three constraint equations for the "longitudinal" components of $\pi^{ij}$ by introducing a Fourier decomposition and expanding in a Neuman series. Since the original first three constraints form a function group, we conclude that in the "solved" form they form a system of involution. We can thus conclude that there exists a canonical transformation which reduces the first three constraints to the form $\pi_{11}{}^{i}=0$. It can also be argued that it is possible to reduce the fourth constraint to the form of a momentum density equaling zero although no procedure has as yet been found to effect the reduction.

**E14. Equation of Motion and the Dynamical Variables of General Relativity.** J. N. GOLDBERG, *Aeronautical Research Laboratory.*—The essential point of the Einstein, Infeld, and Hoffmann approximation method is that the requirement of slow motion splits the field equations into two sets: (1) equations which permit a solution for an arbitrary motion and (2) equations in which the time development of the field is essential. The approximation method orders the equations so that set (1) is to be solved first. Certain consistency conditions in the form of surface integral must then be satisfied before (2) can be solved. These consistency conditions determine the motion of the sources. Although the surface integrals have been formulated without recourse to an approximation method the general problem of motion has not been solved. To do so, one must know the dynamical variables of the gravitational field. The dynamical variables are that part of the field whose time development is determined by the field equations. Thus, the full field equations should also split into two sets and the dynamical variables should appear only in set (2). This program has been carried out in the linearized theory without the assumption of slow motion. It should be noted that these dynamical variables are precisely those field variables which become the quantum field operators.

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## WEDNESDAY AFTERNOON AT 2:00

## Panel Room

## (F. AYZENBERG-SELOVE presiding)

## *Nuclear Energy Levels*

**EA1. $Li^6(d,He^3)$ and $Li^6(d,t)$ Reactions.*** E. W. HAMBURGER AND J. R. CAMERON, *University of Pittsburgh.*—Metallic $Li^6$ targets were bombarded with 15-Mev deuterons; the outgoing particles were magnetically analyzed and detected in nuclear emulsions and scintillation counters. The high energy portions of the triton and $He^3$ spectra were measured over energy ranges of ~5 Mev at ten angles from 9.5° to 70° (lab.). All spectra show a broad peak at $Q\sim 0.8$ Mev and a slowly varying continuum at lower energies. At $\theta_L=15°$ the peak cross section for producing tritons is approximately 1.3 millibarns per steradian per 100 kev (in the center-of-mass system); the cross section for producing $He^3$ is 15% larger. The angular distributions of the peaks show a strong forward maximum although the low-energy continua are nearly isotropic. The shapes of the $He^3$ spectra at forward angles can be very well correlated with the $n$-$He^4$ scattering data if a simple pickup mechanism is assumed for the reaction; the angular distribution also can be accounted for by such a mechanism.

* Work done at the Sarah Mellon Scaife Radiation Laboratory assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**EA2. Investigation of the $Be^9(p,n)B^9$ and $Be^9(p,\alpha\gamma)Li^6$ Reactions.*** J. B. MARION,† *University of Maryland,* AND J. S. LEVIN, *Los Alamos Scientific Laboratory.*—A time-of-flight study has been made of the neutrons and $\gamma$ rays from the proton bombardment of beryllium in the energy range from 2.3 to 5.4 Mev. Excitation curves for the $Be^9(p,n_0)B^9$ reaction at 0° and 90° show the well-known resonances at 2.56 and 4.6 Mev in addition to a broad maximum near 3.5 Mev; the $\gamma$-ray curve shows peaks at the same energies. The 3.5- and 4.6-Mev resonances are tentatively assigned to $p$- and $d$-wave states having $(J=2^+, T=1)$ and $(J=3^-, T=1)$, respectively. The cross section for the production of continuum neutrons is appreciable for proton energies above 3 Mev. These neutrons appear to result largely from the $Be^9(p,p')Be^{9*}$-$(n)Be^{8*}$ reaction involving the 2.43-Mev state in $Be^9$ and the broad 2.9-Mev state in $Be^8$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Summer visitor Los Alamos Scientific Laboratory, 1957.

**EA3. Inelastic Proton-Gamma Angular Correlation.*** HARRY S. ADAMS AND NORTON M. HINTZ, *University of*

*Minnesota.*—The angular correlation of the gamma ray and the inelastic proton scattered from the 4.43-Mev level in $C^{13}$ has been measured for an incident proton energy of 40 Mev. Preliminary data have been obtained for proton angles of 30°, 45°, 60°, and 80°. The data have not been corrected for the effects of finite geometry and have been fitted by a least squares procedure to $W(\theta_\gamma)=A+B\sin^2(\theta_\gamma-\theta_a)$ which is the form predicted by Levinson and Banerjee.[1] For the proton angles measured, the symmetry angles, $\theta_a$, agree very closely with the classical recoil angles. A comparison with the direct-interaction model of Levinson and Banerjee will be made.

| $\theta_p'$ | $A/B$ | $\theta_a$ |
|---|---|---|
| 30° | 0.63 ±0.06 | 68.2° ±2° |
| 45 | 0.38 ±0.04 | 62.5 ±2 |
| 60 | 0.23 ±0.03 | 55.3 ±2 |
| 80 | 0.26 ±0.03 | 46.4 ±2 |

* Supported in part by the U. S. Atomic Energy Commission.
[1] M. K. Levinson and C. A. Banerjee, Ann. Phys. III, 67 (1958).

**EA4. Inelastic Scattering of Protons from $C^{13}$.*** T. H. Braid and J. L. Yntema, *Argonne National Laboratory.*—By degrading the energy of the 10.8-Mev proton beam from the Argonne cyclotron we have measured the scattering from the 4.43-Mev level of $C^{13}$ in the range 10 to 10.8 Mev. There is a strong resonance in the inelastic cross section near 10.8 Mev. This is most evident at 90° to the beam direction, where the differential cross section at 10.8 Mev is 3 times as large as at 10.5 Mev. The variation at 30° and 130° to the beam direction is less than 20% in the same energy range. Angular correlations between the scattered proton and the de-exciting $\gamma$-ray have been measured on this resonance for $\theta_p=20°$, 30°, 60°, 90°, and 130°. The correlations consist of a $\sin^2 2\theta_\gamma$ part to be expected of a direct interaction process[1,2] and an isotropic component. At $\theta_p=90°$ the $\sin^2 2\theta_\gamma$ component is weak compared with the isotropic part; at the other measured angles it is stronger or of comparable magnitude. However, at all values of $\theta_p$ the symmetry angle of this component differs widely from the direction of the recoil nucleus.[1]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] G. R. Satchler, Proc. Phys. Soc. (London) **A68**, 1037 (1955).
[2] M. K. Banerjee and C. A. Levinson, Ann. Phys. 2, 499 (1957).

**EA5. Angular Distributions of Protons from the $C^{14}(d,p)C^{15}$ Reaction.*** W. E. Moore† and J. N. McGruer, *University of Pittsburgh.*—Using 14.9-Mev deuterons on an 80% enriched $C^{14}$ target, proton groups corresponding to the $C^{15}$ ground, 0.75-, 3.1-, 5.9-, 6.4-, and 7.3-Mev states have been observed and angular distributions determined for $\theta(\text{lab})=2°$ to 90°. Approximate cross sections are 6.2, 35.8, 0.21, 0.35, 2.1, and 0.60 mb/steradian, respectively, at $\theta(\text{lab})=14°$. The angular distributions of the ground state and the 0.75, 6.4, and 7.3-Mev excited states exhibit strong forward maxima. The experimental data have been compared with the theory of Butler and best agreement is obtained using $1_n=0$, $r_0=4.0f$ for the ground state and $1_n=2$, $r_0=5.4f$ for the first excited state. These $1_n$ values are consistent with the predictions $J^\pi=\frac{1}{2}^+$ and $\frac{3}{2}^+$ by Halbert and French.[1] Reduced widths determined from these data are 0.083 and 0.030, respectively.

* Work done at the Sarah Mellon Scaife Radiation Laboratory assisted by the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at Knolls Atomic Power Laboratory, Schenectady, New York.
[1] J. B. French (private communication, 1958).

**EA6. Angular Distributions of Deuterons from the $C^{14}(d,d')C^{14}$ Reaction.*** J. C. Armstrong, W. E. Moore, and A. G. Blair, *University of Pittsburgh.*—Using an 80% enriched $C^{14}$ target, and incident deuterons of 14.9 Mev, angular distributions of inelastically scattered deuterons from known $C^{14}$ levels at 6.72-, 7.35-, and 8.32-Mev excitation were obtained. The angular distribution of a previously unreported level at 7.01-Mev excitation was also obtained. These levels display forward peaking and have approximate cross sections at $\theta(\text{lab})=25°$ of 1.04, 0.45, 0.58, and 0.83 mb per steradian, respectively. The 6.09, 6.59, and the unresolved 10.43 and 10.50 levels were also observed with approximate cross sections of 0.25, 0.14, and 0.20 mb per steradian, respectively, at $\theta(\text{lab})=25°$. The $C^{14}$ 6.89 level was not observed.

* Work done at the Sarah Mellon Scaife Radiation Laboratory assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**EA7. Scattering of 19-Mev Alpha Particles by $N^{14}$.*** W. D. Ploughe, E. Bleuler, and D. J. Tendam, *Purdue University.*—The elastic and inelastic scattering of 19-Mev alpha particles from spectroscopically pure $N^{14}$ has been measured using nuclear plates as detectors. The elastic angular distribution, measured every 2.5° from 12.9° to 158.2° (cm), exhibits a diffraction-like pattern similar to those found in $C^{12}$ and $O^{16}$ at the same alpha energy. The oscillations are somewhat less pronounced, especially at angles greater than 90°. This may indicate a nuclear-structure dependence of the elastic scattering. Minima are found at 29°, 47°, 134°, and a somewhat broader minimum at 101°. The transition to the 2.31-Mev ($0^+$) state which is isotopic-spin forbidden is not observed. An upper limit of the intensity of this transition will be given. The angular distribution of the inelastic group leading to the 3.95-Mev ($1^+$) state is currently being measured and will be reported at the meeting.

* Supported in part by the U. S. Atomic Energy Commission.

**EA8. $F^{19}(\alpha,p)Ne^{22}$ and $C^{13}(\alpha,p)N^{16}$ Angular Distributions at $\sim$19 Mev.*** J. R. Priest, D. J. Tendam, and E. Bleuler, *Purdue University.*—The angular distributions of the proton groups from the reaction $F^{19}(\alpha,p)Ne^{22}$ which leave the $Ne^{22}$ nucleus in the ground state, the first excited state, and the second excited state have been measured every 5° from $\sim$12° to 170° (c.m.) using $\frac{1}{4}$-mil Teflon films as targets. The angular distributions are peaked in both the extreme forward and extreme backward angles, the cross sections being comparable in these regions. Secondary maxima are observed in the angular distributions of the first and second excited state proton groups. However, counting statistics in the ground-state angular distribution are so poor that nothing definite can be said about the secondary maxima. The angular distribution of the ground-state protons from the reaction $C^{13}(\alpha,p)N^{16}$ has been measured every 5° from 25° to 155° (c.m.) using $\frac{1}{4}$-mil polyethylene films as targets. The main feature of the angular distribution is the rise in cross section in the backward angles beginning at $\sim$80°. The cross section at 155° is $\sim$ five times that at 55° where a secondary maximum occurs.

* Supported in part by the U. S. Atomic Energy Commission.

**EA9. Energy Levels of $Na^{23}$ from the $Ne^{22}(p,\gamma)$ Reaction.*** J. J. Singh, V. W. Davis, and R. W. Krone, *University of Kansas.*—The gamma-ray excitation function of the $Ne^{22}(p,\gamma)$ reaction has been investigated in the energy range of 600 to 1800 kev. Aside from previously reported resonances,[1,2] new resonances were observed at proton energies of 1.553, 1.593, 1.621, 1.628, 1.721, and 1.833 Mev. The pulse height spectra were studied in detail at all the prominent resonances. Various cascades leading through well-known states of $Na^{23}$ were identified. Ground-state transitions were observed only at the 859-, 904-, and 954-kev resonances. These as well as all the other resonances show the two-step transition through the first excited state at 439 kev, while in no case was a cascade through the second excited state at 2.08 Mev observed. Various alternate decays have been identified and their relative intensities determined.

* This work has been supported in part by the United States Atomic Energy Commission.
[1] Brostrom, Huus, and Koch, Nature 162, 695 (1958).
[2] Thornton, Meads, and Collie, Phys. Rev. 109, 480 (1958).

**EA10. Violation of the Isotopic Spin Selection Rule in the $Ca^{40}(d,\alpha)^{38}$ Reaction.*** W. PARKER ALFORD AND Y. HASHIMOTO, *University of Rochester*.—The $Ca^{40}(d,\alpha)K^{38}$ reaction leading to the ground state and first excited state of $K^{38}$ has been studied for deuteron energies from 3.3 to 4.1 Mev. The ground-state transition is on the average about ten times as intense as that to the first excited state, confirming the assignment of the latter as the $0^+T=1$ analog of the $A^{38}$ ground state. An analysis of these results indicates that the $(d,\alpha)$ reaction between two states of zero spin and the same parity is strongly inhibited by angular momentum selection rules. When this is taken into account, it appears that the isotopic spin-selection rule reduces the cross section for the "forbidden" transition by a factor of about two. This rather severe violation of the I spin selection rule can probably be accounted for by Coulomb effects in the high-excited states of the compound nucleus.

* Work supported by the U. S. Atomic Energy Commission.

**EA11. Search for Double Gamma Emission from the First Excited State of $Ca^{40}$.*** M. NESSIN, K. E. EKLUND, AND T. H. KRUSE, *Columbia University*.—A search was made for the double gamma emission predicted[1] in the $0^+$—$0^+$ ground-state transition from 3.35-Mev state of $Ca^{40}$ excited by proton bombardment. Excitation functions were observed over the 5.02 and 5.08-Mev resonances[2] for annihilation quanta coincidences from the pair decay mode and for gammas of energy between 2.4 and 3.2 Mev. The nonresonant part of the high-energy gamma yield was subtracted out. Since the remainder might be due to ground state transitions from the 3.73 and 3.90-Mev $Ca^{40}$ states, only an upper limit could be calculated for the yield of this portion of the double gamma spectrum. The total double gamma yield was then calculated for various assumed spectral shapes. By comparison with the calculated total pair yield at the resonance peak, an upper limit of 1:1 was placed on the ratio $\Gamma_{\gamma-\gamma}/\Gamma_{\pi}$. A similar excitation function of coincidences between gammas of energies 1.4 and 1.95 Mev gave a limit of the same magnitude, where the effect observed could be ascribed to scattering of higher energy gammas.

* This work was partially supported by the U. S. Atomic Energy Commission.

[1] D. P. Grechuklin, J. Exptl. Theoret. Phys. (U.S.S.R.) 5, 846 (1956).
[2] R. D. Bent and T. H. Kruse, Phys. Rev. 109, 1240 (1958).

**EA12. Low-Lying Levels in $Sc^{41}$ and $Sc^{43}$.*** H. S. PLENDL AND F. E. STEIGERT, *Yale University*.—The reactions $Ca^{40}(\alpha,n)Sc^{41}$, and $K^{39}(\alpha,n)Sc^{42}$ were studied using the 4-Mev deuterons and 8-Mev alpha particles from the Yale cyclotron. The reaction neutrons were observed in nuclear emulsions from 0° back to 150°. Runs were taken both with and without Mylar radiator foils. In the first reaction, three groups were assigned to levels in $Sc^{41}$ with $Q$ values of $-0.57$, $-2.43$, and $-2.54$ Mev. The angular distributions can be fit with Butler distributions with $r_0=6.0$ fermi and $l=3,1,1$, respectively, superimposed upon a high level isotropic cross section. These would correspond well with the comparable groups from $Ca^{40}(d,p)Ca^{41}$.[1] Additional groups at $Q=-1.13$ and $-1.41$ Mev were also observed. These may be due to impurity reactions, however. Three groups of neutrons were observed in the second reaction corresponding to $Q$ values of $-5.88$, $-6.27$, and $-6.53$ Mev, respectively. An extremely low reaction cross section was observed for this latter reaction.

* This work was supported by the Office of Naval Research.

[1] C. K. Bockelman and W. W. Buechner, Phys. Rev. 107, 1366 (1957).

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## WEDNESDAY AFTERNOON AT 2:00

## Boston Room

## (R. J. EMRICH presiding)

## *Fluid Dynamics I*

**F1. Exploded Wire as a Source for High Temperatures and Strong Shock Waves.** V. E. SCHERRER, R. C. O'ROURKE, C. B. DOBBIE, AND I. M. VITKOVITSKY, *U. S. Naval Research Laboratory*.—It has been shown[1] previously that, when the "discharge pause" has been suitably eliminated from wire explosions, the wire should heat up to very high temperatures. Several examples of strong shock waves generated from such wire explosions will be shown including a typical picture of a wire explosion in one arm of a Mach-Zehnder interferometer taken with high time resolution.

[1] O'Rourke, Scherrer, and Dobbie, Bull. Am. Phys. Soc. Ser. II, 2, 47 (1957).

**F2. Pressure Dependence of the Visible Radiation Intensity from Shock Heated Air.** I. M. VITKOVITSKY, R. C. O'ROURKE, V. E. SCHERRER, AND C. B. DOBBIE, *U. S. Naval Research Laboratory*.—In continuation of our study of phenomenon associated with wires which are exploded electrically,[1] a comparison was made of the intensities of radiation emitted by the shock heated optically transparent air and that emitted by air excited with an alpha-particle beam[2] as a function of ambient air density. The pressure range was from 2 to 760 mm Hg in the data to be presented. It is found that the pressure dependence is strikingly similar in both cases. A simple equation from the discussion of collision induced quenching of excited states in Massey and Burhop[3] can be used to describe the intensity as a function of pressure if one uses appropriate experimentally determined constants.

[1] O'Rourke, Scherrer, and Dobbie, Bull. Am. Phys. Soc. Ser. II, 2, 47 (1957).
[2] A. Ward, Proc. Phys. Soc. (London) A67, 841-846 (1954).
[3] Massey and Burhop, *Electronic and Ionic Impact Phenomenon* (Clarendon Press, Oxford, 1952), p. 418.

**F3. Radiation from Nitrogen Shock Front.*** P. HAMMERLING, J. D. TEARE, AND B. KIVEL, *Avco Research Laboratory*.—Calculations have been made of the radiation behind strong shock waves in nitrogen. The time history of the radiation during the approach to thermal equilibrium is obtained numerically by including along with the shock equations the effects of finite rates for dissociation, vibration, dissociative recombination, and charge exchange. The rates used are extrapolated from the most recent experiments known to the authors. Under the conditions considered: $M_s=13$ to 17, $p_1=1$ cm, 1 mm, the dominant radiation in the early stages is from the $N_2^+$ first negative system. At the lower $M_s$ and higher $p_1$, this radiation can be equalled or even exceeded by the intensity from the $N_2$ first positive system at equilibrium. With the rates used equilibrium at the local temperature is reached very quickly compared to the resolving time of current experiments (0.2 μsec). The calculations are quite sensitive to the rates. For example at $M_s=15$, $p_1=1$ mm, a reduction of the dissociation rate by a factor of five causes

the radiation to peak at about a factor 2 later in time, and hence, reach local equilibrium later. A similar effect occurs in proportion to changes in density. The interpretation in this manner of measured radiative relaxation experiments yields a knowledge of vibration and dissociation rates.

* This research was sponsored by the Ballistic Missile Division, Air Research and Development Command, U. S. Air Force.

**F4. Spectrographic Studies of Shock Fronts in Nitrogen.*** JOHN C. CAMM AND JAMES C. KECK, *Avco Research Laboratory.*—The time dependence of the radiation from $N_2^+$ molecules formed by the passage of a strong shock through nitrogen has been studied in order to obtain information about the chemical and electronic processes and rates in nitrogen. Radiation from the 0,0 band of $N_2^+$ at 3914 A was measured in a shock tube with a recording monochromator having a response time of 0.2 $\mu$sec. Under typical test conditions, such as those produced by a shock having a speed of Mach 18 passing through nitrogen at a pressure of one millimeter, the system response time is the equivalent of 1.3 mm in the shock and 2.6 $\mu$sec in particle time. A spectrogram of the shock was made simultaneously by using the "race track" technique, which provides a two-dimensional spectrogram with wavelength in one direction and distance from the shock front in the other. The spectrogram was used to identify the radiating species and to monitor the radiation from impurities. Radiation overshoots at the shock front were observed for the species $N_2^+$,$N_2$ (2nd positive system), CN, and NH. Weak radiation overshoot in the red region is tentatively identified as the $N_2$ first positive system. Comparison of the experimental results will be made with the theoretical results of the preceding abstract.

* This research was sponsored by the Ballistic Missile Division, Air Research and Development Command, U. S. Air Force.

**F5. Theory of Wave Interaction with Gas "Bubbles" in a Gas Flow.*** GEORGE RUDINGER, *Cornell Aeronautical Laboratory.*—Small flow regions where the density is different from that of the main stream do not follow an accelerated motion of the latter.[1] For instance, if air containing a helium "bubble" is accelerated by a shock wave, the bubble moves about 25% faster than the air. A theory of this phenomenon is presented. The bubble is first considered as a solid particle which experiences a buoyancy force in the acceleration field. A gas bubble cannot maintain the resulting motion relative to the surrounding gas and is quickly transformed into a vortex. This process absorbs part of the bubble energy and thus modifies the relative velocity. The ratio of the final bubble velocity to that of the surrounding gas depends on the density ratio of the two gases and on the shape of the bubble, but not on the acceleration. Experimental results with $H_2$, He, and $SF_6$ bubbles in air accelerated by weak shock waves agree well with the theoretical predictions.

* This work was supported by the Office of Naval Research through Project Squid.

[1] G. Rudinger and L. M. Somers, Bull. Am. Phys. Soc. Ser. II, **3**, 285 (1958).

**F6. Leading Edge Slip Flow and Shock Wave Boundary Layer Interaction on a Flat Plate in Hypersonic Flow.** H. T. NAGAMATSU* AND R. E. SHEER, JR., *General Electric Research Laboratory.*—An investigation was conducted on the flow over a flat plate with a sharp leading edge in the test section of a hypersonic shock tunnel for the flow Mach number range of 10 to approximately 26. Static pressure in the test section varied from a few microns to 1 millimeter of mercury and the Knudsen number, ratio of the mean free path to the leading edge radius, varied from about 0.1 to 1.5. Slip flow effects at the sharp leading edge were observed in that the leading edge shock wave was delayed in forming on the plate. The slip increased with the free stream flow Mach number and with the mean free path of the air ahead of the model. In the strong interaction zone, the viscous region extended from the plate to the shock wave and there was no apparent inviscid region between the shock wave and the boundary layer. At the highest flow Mach number that was tested, the induced pressure behind the shock wave near the leading edge was over 100 times the free stream static pressure. The strong interaction parameter $M^3/(R_e)^{\frac{1}{2}}$ varied from about 1 to approximately 400 and the experimental induced pressure agreed well with that predicted by the interaction theory.[1]

* Also, Rensselaer Polytechnic Institute.

[1] T. Y. Li and H. T. Nagamatsu, J. Aeronaut. Sci. **20**, 345 (1953).

**F7. Theoretical Aerodynamic Stability of Wedge-Shaped Air Foils at Extremely High Altitudes.** S. A. SCHAAF, *University of California, Berkeley.*—Theoretical expressions are obtained for axial, normal, and pitching moment coefficients for slender and blunt wedge-shaped air foils in both free molecule flow and in slip flow. The dependence of these coefficients on Mach number, Reynolds number, and the thermal boundary conditions are shown. The very great difference between wind tunnel tests and free flight performance are discussed.

**F8. Incorrectness of Prandtl's Theory of Steady Turbulent Flow of Water through Pipes.** F. J. BELINFANTE, *Purdue University.*—According to Prandtl, the velocity $u$ at a distance $y$ from the wall would be determined by $\tau_0(1-y/R)=\mu du/dy+\rho l^2(du/dy)^2$ with $\mu$ = viscosity, $\rho$ = density, $\tau_0$ = shear at wall, $R$ = radius of pipe, $l$ = some function of $y$ and of Reynolds' number $N=2\rho u_M R/\mu$, with $l(y=0)=0$. Customarily one integrates this equation for $l\approx 0$ near the wall and for $\mu\approx 0$ elsewhere, fitting the solutions together at $y=\delta$. From the resulting velocity distribution $u(y)$, Kármán and Nikuradse derive relations $1/\sqrt{\lambda}=A+B\log(N\sqrt{\lambda})$ between $N$ and the resistance coefficient $\lambda=8\tau_0/\rho u_M^2$. Agreement with the experimental $\lambda,N$ relation is obtained by choice of the adjustable constant $\delta$. However, obviously Prandtl's differential equation for $u(y)$ could be solved rigorously without introducing any adjustable constant, using for $l^2$ the function of $y$ and $N$ experimentally determined as $\tau_0(1-y/R)/\rho(du/dy)^2$ with for $y\to 0$ a linear approach to $l\to 0$. If Prandtl's idea were correct, this should give the correct $\lambda,N$ relation automatically. We find, however, that such a procedure leads to values of $(-A)$ which are far too large, showing the inadequacy of Prandtl's hypothesis.

**F9. Laminar Jet Mixing of Electrically Conducting Fluid in a Transverse Magnetic Field.** S. I. PAI, *University of Maryland.*—The effect of laminar jet mixing of an electrically conducting incompressible and viscous fluid under an applied transverse magnetic field is investigated. If the applied magnetic field varies inversely to $x^{\frac{1}{2}}$, where $x$ is the distance along the axis of the jet, similar solution may be obtained. The velocity of the jet increases with the factor $Q=9(\sigma/\rho)B_1^2$ where $\sigma$ is the electrical conductivity, $B_1$ is proportional to the magnetic induction, and $\rho$ is the density of the fluid. The spread of the jet is inversely proportional to $\sqrt{Q}$. The jet mixing under a uniform magnetic field is also discussed. The increment of the velocity in the jet mixing region due to the external magnetic field also increases with $Q$.

**F10. An Extended Reynolds Analogy.** WILLIAM SQUIRE, *Bell Aircraft Corporation.*—Heat and mass transfer to an incompressible turbulent flow in a smooth pipe is treated theoretically using defect laws for the velocity and temperature (or concentration) distributions instead of wall similarity laws. The derived expression for the Nusselt number agrees satisfactorily with experiment over a wide range of Reynolds and Prandtl (or Schmidt) numbers including the liquid metal range. One of the assumptions used probably becomes inaccurate at very large Prandtl numbers, but because of an unresolved conflict in the experimental data in this region[1,2]

the nature of the required modification cannot be settled at present.

[1] D. A. Frank-Kamenetskii, *Diffusion and Heat Exchange in Chemical Kinetics* (Princeton University Press, Princeton, New Jersey, 1955).
[2] R. E. Deissler, NACA Report 1210 GPO (1955).

**F11. Sonically Induced Microstreaming and Its Effects on Surface Phenomena.*** W. L. NYBORG, F. J. JACKSON, AND E. C. TANNER, *Brown University.*—A consequence of nonlinearity in the hydrodynamical equations is that flow fields generated by sinusoidally vibrating boundaries exhibit time-independent circulation superposed on the oscillatory flow. Of special interest here is the steady flow induced in the immediate vicinity of boundaries. Typical speeds in this near-boundary flow tends to have their greatest values at points where there exist steep gradients of the near-surface irrotational velocity amplitude. Arrangements will be described in which vibratory sources (10 to 40 kc) are used to generate highly localized eddying near points of interest on a plane surface. Application of this small-scale eddying, or microstreaming, to surfaces at which reactions, transport activity, etc., occur shows promise as a technique for studying flow effects on such surface processes. Preliminary results have been obtained on such diverse phenomena as (1) photographic development, (2) metal etching, and (3) electrode processes.

* This work is supported in part by the Air Force Office of Scientific Research and in part by the National Institutes of Health, Biophysics Section.

**F12. Some New Experimental Results in Turbulent Equilibrium Boundary Layers.** EARL M. URAM AND MURRAY H. ROSENBERG, *United Aircraft Corporation.*—A two-dimensional diffuser for generating and maintaining an equilibrium boundary layer was designed on the basis of an unpublished theory developed by F. Clauser. Detailed velocity and pressure distributions were obtained for two boundary layers, one having a transitional velocity profile at the diffuser inlet, the other having a fully turbulent velocity profile at the diffuser inlet and fulfilling all of the design requirements. Better than two-thirds of the boundary layer with the transitional inlet conditions exhibited equilibrium while the other might be said to exhibit near-equilibrium in two separate regions of its development. Although a conventional straight-wall diffuser with the same inlet conditions and area ratio caused boundary layer separation, neither boundary layer grown in the equilibrium geometry was near separation. The data obtained from these boundary layers and from one other equilibrium boundary layer that was developed on a flat plate indicate that a unique correspondence between $xdp/qdx$ and $\theta dp/\tau_w dx$ need not exist for equilibrium to be maintained, and that evidently the requirement that $\theta dp/\tau_w dx$ be constant is not sufficient to describe the equilibrium condition.

**F13. Theory of Decaying Homogeneous Turbulence.** ROBERT G. DEISSLER, *Lewis Research Center, NASA* (introduced by James W. Blue).—In a previous paper[1] the decay of homogeneous turbulence before the final period was analyzed by utilizing two and three point correlation equations. The set of equations was made determinate by neglecting the quadruple correlations in the three point equations. In the present paper the theory is extended to earlier times by retaining the quadruple correlation terms and considering a four point correlation equation. The set of equations is made determinate in this case by neglecting the fifth-order correlations in the four point equation. The equations are converted to spectral form by taking their Fourier transforms. Results obtained include relations for the energy decay and for the energy spectrum function, the latter of which gives contributions from various wave numbers or eddy sizes to the total energy. In general the effect of the higher order terms in the correlation or spectral equations is to excite the high wave number (small eddy) regions of the spectrum by transferring energy into those regions. The contributions from the higher order terms die out faster than those from the terms of lower order.

[1] R. G. Deissler, Phys. Fluids 1, 111–121 (1958).

**F14. A Random Walk with Both Lagrangian and Eulerian Statistics.*** J. L. LUMLEY AND S. CORRSIN, *Johns Hopkins University.*—An unsolved turbulence problem is that of relating the (Lagrangian) statistical functions following a fluid particle to the (Eulerian) statistical functions of the flow field in space-time. Lacking a solution to this physical problem, we have devised a random walk which displays both Lagrangian and Eulerian features. (Generalized random walks previously considered are purely Lagrangian.[1]) The technique is to assign the transition probabilities to the space-time lattice points rather than to the particle itself. In the one-dimensional walk the Eulerian and Lagrangian velocity autocorrelations have been found.[2] Now the characteristic function of particle displacement has been calculated, and possible continuum limit forms for the probability density equation have been deduced. One of these turns out to be the telegraph quation, given by Goldstein[1] as the limit of a different kind of random walk.

* Supported by The Mechanics Branch, U. S. Office of Naval Research.
[1] Goldstein, Quart. J. Mech. Appl. Math. IV, Pt. 2 (1951).
[2] Lumley and Corrsin, *Proceedings of the International Symposium on Atmospheric Diffusion and Air Pollution* (Academic Press, Inc., New York, to be published).

***Business Meeting of the Division of Fluid Dynamics***

(To be held during this session whenever the Chairman elects.)

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WEDNESDAY AFTERNOON AT 2:00

Grand Ballroom

(M. A. BIONDI presiding)

***Symposium of the Division of Electron Physics***

***Physics of the Upper Atmosphere***

**FA1. Satellite Measurements of Density and Cosmic Radiation in the Upper Atmosphere.** ROBERT JASTROW, *U. S. Naval Research Laboratories.* (30 min.)

**FA2. Ionospheric Properties Deduced from Rocket and Satellite Data.** HERBERT FRIEDMAN, *U. S. Naval Research Laboratories.* (30 min.)

**FA3. Mechanisms of Energy Transport to the Earth from the Sun.** SYDNEY CHAPMAN, *University of Alaska and University of Colorado.* (30 min.)

***Business Meeting of the Division of Electron Physics***

WEDNESDAY AFTERNOON AT 2:15

Governor Clinton Hotel

(G. FEHER presiding)

## *Paramagnetic Resonance; Masers; Semiconductors I*

**G1. Paramagnetic Resonance Spectrum of $Cr^{+++}$ in Emerald.*** J. E. GEUSIC, M. PETER, AND E. O. SCHULZ DU BOIS, *Bell Telephone Laboratories.*—Paramagnetic resonance for the $Cr^{+++}$ ion in emerald has been observed at $X$ band, $K$ band, and $M$ band. The observed paramagnetic resonance spectrum is described by a spin Hamiltonian of the form

$$\mathcal{H}=\beta[g_{11}H_zS_z+g_\perp(H_xS_x+H_yS_y)]+D[S_z^2-1/3S(S+1)],$$

with $2D=-53.6\pm0.1$ kmc/sec, $g_{11}=1.973\pm0.002$, and $g_\perp=1.97\pm0.01$. This value of $2D$ for $Cr^{+++}$ in emerald is, to date, the largest zero field splitting which has been reported for the $Cr^{+++}$ ion in any crystal.

* This work is partially supported by the Signal Corps.

**G2. Possible New Mode of Operation for Four-Level Paramagnetic Masers.*** GEORGE MAKHOV, *University of Michigan* (introduced by R. W. Terhune).—It is suggested that in a four-level maser system the simultaneous use of 1–3 and 2–4 saturating transitions (termed "push-pull" pumping) may yield stimulated emission resulting from transitions between levels 4 and 1. Assume that both pumping transitions are saturated, i.e., $n_1=n_3$, and $n_2=n_4$; furthermore, assume that the energy level separations and the associated relaxation times are such as to make $n_3>n_1$. Then, $n_4>n_1$, implying that stimulated emission of frequency $\nu_{41}$ should occur. Microwave power emitted by the paramagnetic crystal would be, in Bloembergen's notation

$$P=\frac{Nh^2}{4kT}\frac{\omega_{32}\nu_{32}-\omega_{21}\nu_{21}-\omega_{41}\nu_{41}}{\omega_{12}+\omega_{23}+\omega_{14}+\omega_{34}+W_{41}}W_{41}.$$

An attempt was made to test the above mode of operation using ruby as the active medium. The operating point was as follows: $\theta=54°44'$; $H=1150$ gauss; $\nu_{13}=\nu_{24}=12.4$ kmc/sec; and $\nu_{41}=17.8$ kmc/sec. Inversion of populations of levels 1 and 4 was not achieved, although saturation of the 1–4 transition through 1–3 and 2–4 transitions was observed. The two pumping transitions were saturated, hence apparently the condition $n_2>n_1$ was not realized, due to relatively slow relaxation associated with the 3–2 transition.

* This work was supported by Project MICHIGAN administered by the U. S. Army Signal Corps).

**G3. Maser Action in Ruby in the 21-cm Region.*** F. R. ARAMS AND S. OKWIT, *Airborne Instruments Laboratory*, AND A. A. PENZIAS, *Columbia University.*—A three-level ruby maser employing a partially superconducting fixed frequency cavity was operated at Columbia University. It employed the $\frac{1}{2}\leftrightarrow-\frac{1}{2}$ and $-\frac{1}{2}\leftrightarrow-\frac{3}{2}$ transitions (employing the low field notation) for amplifying and pumping frequencies respectively. It was operated at low magnetic fields oriented at 67° relative to the crystal axis. A tunable maser was developed concurrently at Airborne Instruments Laboratory. Operation was obtained without the use of a superconducting cavity using the $-\frac{3}{2}\leftrightarrow\frac{1}{2}$ and $\frac{1}{2}\leftrightarrow\frac{3}{2}$ transitions at high magnetic fields oriented at 90° to the crystal axis. Operating parameters of the two masers will be given and the types of operation will be compared.

* Work supported in part by the Department of Defense and in part jointly by the Signal Corps, the Office of Naval Research, and the Air Force Office of Scientific Research.

**G4. Ordered Operator Approach to the Theory of Spin-Lattice Relaxation.*** ROBERT W. HELLWARTH, *Hughes Research Laboratories.*—We have reported previously[1] a quantum treatment of dissipation which employs an ordered operator technique that avoids the use of perturbation theory. This formalism has been applied to the problem of spin-lattice relaxation to obtain an exact, parametrically ordered, expression for the density matrix of a spin coupled to a phonon bath. The expression is a result of integrating the phonon coordinates out of the expression for the combined spin-lattice density matrix. From this "entangled" form of the spin density matrix, the lattice contribution to the line shape (and shift) and certain symmetry properties may be obtained. The transient behavior of the spins may be derived by the "disentanglement" of the density operator into conventionally ordered form. One approximate method for doing this reproduces the various orders of perturbation theory. Another approach yields integro-differential equations for various expectation values. With one such approximate differential equation and specific lattice models various transient decay functions have been obtained.

* Supported in part by the U. S. Signal Corps.
[1] R. W. Hellwarth, Bull. Am. Phys. Soc. Ser II, 3, 339 (1958).

**G5. Electron Spin-Lattice Relaxation in Dilute Potassium Chromicyanide.*** P. E. WAGNER, J. G. CASTLE, JR., AND P. F. CHESTER, *Westinghouse Research Laboratories.*—Measurements have been made of the spin-lattice relaxation of the $2\rightarrow3$ line of $Cr^{+++}$ in $K_3Cr_{0.001}Co_{0.999}(CN)_6$ after inversion by field-sweep fast passage at 9.1 kMc/sec. The recovery of the line was monitored to within a few percent of equilibrium with a second field-sweep at increasing times after inversion. A single time constant was found over the whole range. The line was evidently inhomogeneously broadened since a "hole" could be inverted in it. With $H_0$ in the ac plane, the separation between the $2\rightarrow3$ and $1\rightarrow2$ lines was varied by changing $\theta$, the angle between $H_0$ and the $c$ axis. A reduction in $T_1$ was noted at separations less than 450 Mc/sec, amounting to a factor of two at coincidence. The $2\rightarrow3$ line width was $\sim16$ Mc/sec. With $\theta=47.5°$ the measured temperature dependence of $T_1$ in the range 2.2–1.2°K can be represented as $1/T_1=15(n+\frac{1}{2})$ sec$^{-1}$, where $n$ is the average occupation of a phonon mode at the resonant frequency. It is concluded that, in 0.1% chromicyanide, spin-lattice relaxation proceeds via a single phonon process with no bottleneck and that the measured times are true spin-phonon times.

* Supported in part by Wright Air Development Center, U. S. Air Force.

**G6. Paramagnetic Relaxation of Trapped Holes in Alkali Halides.** T. G. CASTNER, *General Electric Research Laboratory.*—Steady-state paramagnetic absorption saturation curves ($V_R\propto\chi''H_1$) have been obtained for the $V_K$ center[1] in LiF, KCl, and KBr at 78°K, 48°K, and 20°K with a 3-cm spectrometer. An extension of Portis' theory[2] for the saturation of an inhomogeneously broadened resonance line has been made for the case the individual spin width is comparable or slightly smaller than the inhomogeneous width based on a Lorentzian shaped spin packet and a Gaussian distribution of spin packets. Analysis of the saturation curves with the extended theory allows the determination of $T_2$, $(T_1T_2)^{\frac{1}{2}}$, and $T_1$ with satisfactory agreement obtained. $T_2$ is found to be considerably shorter than $T_1$ and independent of temperature. The nature of the $T_2$ interaction is discussed. The temperature variation of $T_1$ is found to be in satisfactory agreement with Raman

relaxation due to spin-orbit coupling. Calculations have been made for direct and Raman spin-lattice relaxation of the $V_K$ center for spin orbit and hyperfine coupling of the $V_K$ center spins and phonons. Problems associated with relaxation measurements in the helium range will be considered.

[1] T. G. Castner and W. Känzig, J. Phys. Chem. Solids **3**, 178 (1957).
[2] A. M. Portis, Phys. Rev. **91**, 1071 (1953).

**G7. Electron Spin Resonance Observations of Free Radicals in Polymers.*** KEN HOTTA AND ROY S. ANDERSON, *University of Maryland.*—The mechanism of free radical polymerization of vinyl polymers has been studied by electron spin resonance techniques. Styrene, methyl methacrylate, and vinyl acetate monomers and polymers have been examined by subjecting them, at various stages of polymerization to ultraviolet irradiation. In these experiments radicals were generally observed only when benzoyl peroxide initiator was used. The mechanism of initiator action has been inferred. The initial stage of polymerization has been studied by irradiation of monomer at 77°K. Polymer radicals in the course of reaction have been observed by room temperature irradiation, followed by quenching of samples to 77°K. The gelled state of high polymers showed radicals to be stably occulded in the polymer matrix even at room temperature. Identification of radicals existing at all three stages has been made and will be discussed. Viscosity measurements indicate that polymer molecular weights of $10^4$ to $10^5$ are required for radical occulsion.

* This research has been supported by the Signal Corps of the Department of Defense.

**G8. Spin Resonance of Iron in Silicon.** G. W. LUDWIG, R. O. CARLSON, AND H. H. WOODBURY, *General Electric Research Laboratory.*—Iron in silicon acts as a donor with an electrical level[1] 0.40 ev from the valence band. Samples containing such donor sites were prepared by diffusing iron into silicon crystals at ~1300°C. When the donor sites are filled with electrons a characteristic spectrum is observed. At 10°K it consists of an isotropic line at $g=2.0699$ showing structure which may be due to the 4.7% abundant $Si^{29}$ isotope. The $Fe^{57}$ hyperfine structure is resolved in enriched samples.[2] A second spectrum has been observed which is believed due to empty donor sites. The spectrum consists of five lines which are described by $g=1.998$, $S=\frac{1}{2}$, and a cubic field splitting parameter $a=+37.3\times10^{-4}$ cm$^{-1}$.

[1] C. B. Collins and R. O. Carlson, Phys. Rev. **108**, 1409 (1957).
[2] Ludwig, Woodbury, and Carlson, Phys. Rev. Letters **1**, 295 (1958).

**G9. Spin Resonance Study of Gold-Manganese Pairs in Silicon.** H. H. WOODBURY, R. O. CARLSON, AND G. W. LUDWIG, *General Electric Research Laboratory.*—Pairing of manganese with gold atoms in silicon has been detected and studied by spin resonance techniques. Samples were prepared by simultaneous diffusion of manganese and gold into $p$-type silicon crystals at ~1300°C. The spectrum of any one gold-manganese pair shows axial symmetry about a (111) axis ($g_{\parallel}=2.0$, $g_{\perp}=4.0$), indicating that the pair is oriented along a (111) direction. A tentative model is that the Au is substitutional and the Mn is bound tightly to it as an interstitial. The manganese hyperfine structure is described by $A=\pm60$, $B=\pm96$, and a quadrupole interaction $P=0.9$, all in units of $10^{-4}$ cm$^{-1}$. Below 20°K each manganese hyperfine line is split by hyperfine interaction due to the gold nucleus. The angular dependence of the gold hyperfine structure is unusual. However, it can be accounted for it one assumes that the quadrupole interaction of the gold nucleus is much stronger than its magnetic interaction. The electric field gradient at the gold nucleus axial symmetry along the (111) direction. Both the maganese and the gold hyperfine interactions have been studied using electron-nuclear double resonance.

**G10. Spin Resonance of the Charge Carriers in Graphite.** G. WAGONER, *National Carbon Company Research Laboratories.*—Electron spin resonance has been observed in graphite by several authors[1,2] but the nature of the spin centers remained somewhat uncertain. The more detailed observations reported here on purified single crystals conclusively establish that the resonance is due to charge carriers: the absorption has the Dysonian line shape characteristic of conduction electron spin resonance in good conductors; the number of carriers contributing to the resonance agrees, in magnitude and temperature dependence, with the number as given by J. W. McClure's work on the band theory of graphite. The most striking feature of the graphite spin resonance is the large, temperature dependent, $g$-value anisotropy. At room temperature the $g$ value varies from $2.0026\pm0.0002$ to $2.0495\pm0.0002$ as the magnetic field is shifted from perpendicular to parallel to the $c$ axis. The $g$-value anisotropy increases with decreasing temperature, $g_{\parallel}$ becoming 2.127 at 77°K, while $g_{\perp}$ remains constant.

[1] J. G. Castle, Phys. Rev. **92**, 1063 (1953).
[2] Hennig, Smaller, and Yasaitis, Phys. Rev. **95**, 1088 (1954).

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## WEDNESDAY AFTERNOON AT 2:00

## Terrace Room

## (R. L. WALKER presiding)

### *Pions*

**GA1. Photoproduction of Neutral Pions from Hydrogen at Forward Angles.*** K. BERKELMAN,† J. WAGGONER, AND D. R. CORSON, *Cornell University.*—The bremsstrahlung beam of the Cornell Bev synchrotron has been used to study the reaction $\gamma+p\rightarrow p+\pi^0$ over the photon energy range 230 Mev to about 1 Bev, and for center-of-mass pion angles well forward of 90°. The recoil protons, of energies between 10 and 60 Mev, are identified and their energies determined using a range telescope of eight thin plastic scintillators enclosed in a vacuum chamber with the thin liquid hydrogen target. Correlated pulse-height information is obtained by photographing an oscilloscope display and is used to sort out the protons from mesons and electrons. Low-energy data are in agreement with previous emulsion measurements.[1] These, together with results obtained at high energies, will be presented.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Supported by National Science Foundation and Corning Glass Predoctoral Fellowships.
[1] McDonald, Peterson, and Corson, Phys. Rev. **107**, 577 (1957).

**GA2. Photoproduction of $\pi^+$ Mesons from Hydrogen in the Region 450–1100 Mev.*** FRANK TURKOT, *Cornell University.*—Positive mesons from the reaction $\gamma+p\rightarrow\pi^++n$ are produced in a liquid hydrogen target by the bremsstrahlung

beam of the Cornell 1.2-Bev synchrotron, momentum analyzed by a strong focusing magnet, and then identified by pulse-height requirements in a four-counter telescope. An excitation curve in the energy range 450–700 Mev and at a laboratory angle of 9° (∼14° in the center of mass) has been obtained. The electron background is made tractable by a shower technique. The cross section decreases very slowly from 12 $\mu$b/sterad at 450 Mev to 10.5±0.8 $\mu$b/sterad at 700 Mev. This forward angle data begin to deviate appreciably from the quadratic cos$\theta$ fit to the previous data[1] at larger angles at an energy of 550 Mev. Another excitation curve in the energy interval 800–1100 Mev and at a laboratory angle of 68° (∼100° in the center of mass) was measured in a search for a possible third resonance. The cross section decreases steeply from 4.5±0.5 $\mu$b/sterad at 800 Mev to 1.17±0.16 $\mu$b/sterad at 1100 Mev with no obvious indication of a resonance.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Heinberg, McClelland, Turkot, Woodward, Wilson, and Zipoy, Phys. Rev. 110, 1211 (1958).

**GA3. Polarization in the Photoproduction of Pions.*** P. L. CONNOLLY AND R. WEILL,† *Cornell University.*—It has been pointed out by Sakurai[1] that a measurement of the polarization of the recoil proton from photoproduction of the neutral pion would serve to distinguish between two possible theories of high-energy photoproduction. Feld and Maglic[2] have shown that nuclear emulsions can serve as an efficient analyzer for proton polarization. The bremsstrahlung beam from the Cornell synchrotron was allowed to strike a liquid hydrogen target. Protons of 150-Mev kinetic energy at a laboratory angle of 40° are selected by a strong focusing bending magnet. A stack of Ilford G-5 emulsions was placed at the exit end of this magnet. Proton scatterings to the "left" and "right" are then detected in this stack. Results will be discussed.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave of absence from "laboratoire de recherches nucleaires E. P. U. L.," Lausanne.
[1] J. J. Sakurai, Phys. Rev. Letters 1, 258 (1958).
[2] B. T. Feld and B. C. Maglic, Padua-Venice Conference and private communication.

**GA4. Photoproduction of $\pi^+$ Mesons Very Near Threshold.*** ANGELA BARBARO, *University of Rome,* AND E. L. GOLDWASSER, AND D. CARLSON-LEE, *University of Illinois.*—An experiment has been done to measure the absolute value of the $\pi^+$ photoproduction cross section at 160 Mev and at 220 Mev. Preliminary results indicate that at $E_\gamma = 219$ Mev, $(d\sigma/d\Omega)_{90°} = 13.0 \pm 0.8 \times 10^{-30}$ cm²/sterad. At $E_\gamma = 160$ Mev, $(d\sigma/d\Omega)_{90°} = 4.6 \pm 0.5 \times 10^{-30}$ cm²/sterad. The higher energy number is in good agreement with the results published by Beneventano *et al.*[1] The 160-Mev cross section is larger than previously existing experimental results and lies above the extrapolation suggested by Beneventano *et al.* It appears to be in agreement with the theoretical prediction.

* Supported by the Office of Naval Research and the U. S. Atomic Energy Commission and Fulbright and Guggenheim fellowships to Rome.
[1] Beneventano, Bernardini, Carlson-Lee, Stoppini, and Tau, Nuovo cimento 4, 323–356 (1956).

**GA5. Ratio of $\pi^-/\pi^+$ Photoproduction from Deuterium.*** G. NEUGEBAUER, W. WALES, AND R. L. WALKER, *California Institute of Technology.*—Preliminary data have been obtained on the angular distribution and energy dependence of the ratio of negative to positive pions produced in a liquid deuterium target by the bremsstrahlung beam of the CalTech synchrotron. Pions are selected and identified by a momentum analysis in a magnetic spectrometer and by pulse-height discrimination in three counters placed near the spectrometer focus. Protons are eliminated with a Čerenkov counter. The ratio has been studied at pion angles from 10 to 55 degrees in the lab and pion laboratory momenta from 550 Mev/c to 950 Mev/c. For a free nucleon, this corresponds to angles of 20 to 90 degrees in the center of momentum system and to mean inicident photon energies of 600 to 1000 Mev. Data at larger angles and lower pion momenta soon will be available. The ratio $\pi^-/\pi^+$ is approximately one for the lower energies and small angles. However, for photon energies of 900–1000 Mev the ratio $\pi^-/\pi^+$ is approximately one-half with little variation for center of momentum angles between 20 and 90 degrees.

* This work was supported in part by the U. S. Atomic Energy Commission.

**GA6. $\pi^-$-$P$ Scattering in the Sub-Bev Region.*** W. D. WALKER, R. R. CRITTENDEN, J. H. SCANDRETT, AND W. D. SHEPHARD, *University of Wisconsin,* AND J. BALLAM, *Michigan State University.*—We have measured the $\pi^-$-$P$ differential elastic cross sections at energies of 460, 600, and 750 Mev in a propane bubble chamber. These data and those of Willis[1] and Erwin and Kopp[2] make it possible to determine the elastic and inelastic cross sections in the $T = \frac{3}{2}$ state. Recent work on the photoproduction of pions indicates a possible resonance at about 600 Mev.[3] From the magnitude of the $\pi^-$-$P$ cross sections it seems unlikely that there is a resonance in a $J = \frac{3}{2}$ state. It is possible that there is a resonance in a $J = \frac{1}{2}$ state. We have attempted to do a phase shift analysis on the data at 460 Mev. A phase shift analysis at higher energies is very ambiguous because of the large inelastic cross section.

* Supported in part by the U. S. Atomic Energy Commission, a National Science Foundation Grant, and a grant from the Wisconsin Alumni Research Foundation.
[1] W. J. Willis, Ph.d. Thesis, Yale University.
[2] A. R. Erwin and J. Kopp (private communication).
[3] R. R. Wilson and R. L. Walker, Proceedings of the 1958 CERN Conference on High Energy Physics.

**GA7. Asymmetry of Pion Production in the Reaction $p+p \to \pi^+ + p + n$.*** R. MCILWAIN, J. DEAHL, M. DERRICK, J. FETKOVICH, AND T. FIELDS, *Carnegie Institute of Technology.*—The 53% polarized 415-Mev proton beam from the Carnegie Tech synchrocyclotron was used to bombard a liquid hydrogen target. Pions produced to the right and to the left were successively detected by means of their $\pi\mu e$ decay in a six inch propane bubble chamber. Elastically scattered protons were used to monitor the incident beam intensity. The pions which stopped in the chamber had an average c.m. momentum of 0.55 $\mu$c and c.m. production angles between 80° and 105°. A preliminary analysis of 202 events yields a pion asymmetry of $|\epsilon| = 0.22 \pm 0.10$, in the same direction as the previously observed asymmetry for the $(pp,\pi^+d)$ reaction. The similarity between the observed pion asymmetry and that for the $(pp,\pi^+d)$ reaction suggests that their reaction amplitudes are similar, and thus that $^3S$ rather than $P$ states are predominant for the final state nucleons in the $(pp,\pi^+pn)$ reaction at this energy.

* Supported in part by the U. S. Atomic Energy Commission.

**GA8. $\pi^+ - P$ Scattering at Low Energies.*** E. W. JENKINS AND G. E. FISCHER, *Columbia University.*—The Columbia University hydrogen bubble chamber was used to investigate the $\pi^+ - p$ scattering cross section in an energy range from 2.5 to 26 Mev. A total of 950 events were measured, of which 369 were caused by incident pions that would have come to rest in the chamber. Assuming a Chew-Low dependence for $\alpha_{33}$ with parameters $f^2 = 0.088$ and $\omega_0^* = 2.17$, events from the stopping flux yield a preliminary result of $\alpha_3 = 0.109 \pm 0.006\eta$ which is in agreement with recently reported values at this energy.[1] The results of a maximum likelihood calculation for all events and a possible nonlinear momentum dependence of the $s$-wave phase shifts will be discussed.

* This research in part supported by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] Proceedings of the CERN Conference, Geneva, July, 1958.

**GA9. Polarization of Recoil Protons from the Photoproduction of $\pi^0$ Mesons.*** P. C. STEIN, *Cornell University.*—Sakurai[1] has shown that Peierls'[2] assignment of $(D_3^3)$ to the second resonance in meson photoproduction leads to a strong polarization of the recoil protons from the photoproduction of mesons from hydrogen. The polarization was measured by observing the left and right scatterings of the recoil protons by carbon. The minimum proton energy was determined by the range of the proton telescope, and the maximum by the cutoff of the bremsstrahlung beam. Protons at 40° in the laboratory were scattered through an angle of 11°. The peak energy of the Cornell synchrotron was 800 Mev. This kinematically corresponds to a $\pi^0$ angle of 90° in the center of mass, and a mean photon energy of 700 Mev. Results will be given.

* This work supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] J. J. Sakurai, Phys. Rev. Letters 1, 258 (1958).
[2] R. F. Peierls, Phys. Rev. Letters 1, 174 (1958).

**GA10. Panofsky Ratio for Stopped Negative Pions in Hydrogen.*** E. L. KOLLER AND A. M. SACHS, *Columbia University.*—The ratio of mesonic to radiative capture of stopped negative pions in hydrogen, i.e., the Panofsky ratio, provides a useful link in analyzing the results of photoproduction of pions and pion-nucleon scattering. Previous measurements[1] of the Panofsky ratio indicate possible systematic errors in the experimental techniques. The ratio has been remeasured using (a) a lead glass Čerenkov counter of improved resolution to measure the total energy of the gamma rays (±16% for the 129-Mev gamma rays measured in this experiment), (b) time-of-flight measurement of the 180 degree recoil neutrons to determine the shape of the pulse height spectrum of the high-energy gamma ray, and (c) a collimator of variable dimensions to test the possible effect of degradation of the high energy gamma rays in the collimator. The value obtained for the ratio is 1.46±0.10, in good agreement with the Liverpool experiments.

* This work was performed under the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Panofsky, Aamodt, and Hadley, Phys. Rev. 81, 565 (1951); Cassels, Fidecaro, Wetherell, and Wormald, Proc. Phys. Soc. (London) A70, 405 (1957); Kuehner, Merrison, and Turnabene, cf. Cassels *et al.*; Fischer, March, and Marshall, Phys. Rev. 109, 533 (1958).

### *Invited Paper*

**GA11. Elastic Scattering of Pions from Complex Nuclei.** J. RAINWATER, *Columbia University.* (30 min.)

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WEDNESDAY AFTERNOON AT 4:45

Grand Ballroom

(J. W. BEAMS presiding)

### *Business Meeting of the American Physical Society*

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THURSDAY MORNING AT 9:45

Terrace Room

(R. J. PLANO presiding)

**H1. Photoproduction of Pions at High Energies.** R. L. WALKER, *California Institute of Technology.* (30 min.)

**H2. Measurements of the Asymmetry in Sigma-Hyperon Decay.** R. L. COOL, *Brookhaven National Laboratory.* (30 min.)

### *Strange Particles*

**H3. High-Energy $K^-$-Meson Interactions.** R. STEPHEN WHITE, STANLEY C. FREDEN, AND FRANCIS C. GILBERT, *University of California, Livermore.*—Interactions of $K^-$ mesons of 20 to 300 Mev with emulsion nuclei have been studied. fifty-five meters of $K^-$ track below 150 Mev and 40 meters above 150 Mev have been followed. For $K^-$ meson energies from 150 to 300 Mev the $K^-$-meson free-proton scattering cross section is found to be 40 mb from five events and the $K^-$-meson free-proton capture cross section to give a charged $\Sigma^\pm$ hyperon and a $\pi^\mp$ meson is 20 mb from 3 events. The mean free path for $K^-$ interactions on emulsion nuclei increases slowly from 25±3 cm at 20 Mev to 35±5 cm at 300 Mev. The fraction of events with $K^-$ meson inelastic scattering increases from 5% below 150 Mev to 20% above 150 Mev. The distribution in the fractional energy loss is fairly constant. The inelastic events are not included for the rest of this abstract. Below and above 150 Mev, respectively, $\pi^\pm$ mesons are observed in 20% and 35% of the events, $\Sigma$ hyperons (corrected for detection efficiency) in 10% and 30%, $\Sigma^\pm\pi^\mp$ pairs in 5% and 20%. The $\pi^-/\pi^+$ ratios are 18/3 and 8/3, and the $\Sigma^-/\Sigma^+$ hyperon ratios 1.7±0.7 and 1.7±0.7, respectively. The $\pi$ meson energy spectrum is shifted to higher energies for $K^-$ meson energies above 150 Mev. The data are explained in terms of a model previously presented by the authors for explaining $K^-$ captures at rest on nuclei.

**H4. Charge-Exchange Scattering of $K^-$ Mesons on Protons.*** P. NORDIN, A. ROSENFELD, F. SOLMITZ, R. TRIPP, AND M. WATSON, *University of California, Berkeley.*—On scanning 10 000 $K^-$ interactions observed in the Berkeley hydrogen bubble chamber, we have identified 45 charge-exchange scatters in which the $\bar{K}^0$ subsequently decays via $K_1^0 \rightarrow \pi^+ + \pi^-$. The $K$ laboratory-momentum interval investigated was 50 Mev/c to 433 Mev/c. The determination of the momentum

at which the scattering occurs depends sensitively on the $\bar{K}^0$ mass, which is currently under investigation. Since the reaction is endothermic, the cross section rises from threshold. It reaches a maximum of about 15 mb at 150 Mev/c and then decreases to 4 mb at 418 Mev/c. Twenty-seven charge-exchange scatters occur with the $\bar{K}^0$ center-of-mass angle lying in the forward hemisphere, and 18 occur in the backward hemisphere. The mean life of the $K_1^0$ decay mode is measured to be $0.80\pm0.12\times10^{-10}$ sec.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

**H5. Scattering Cross Sections of $K^+$ Mesons on Protons and Neutrons.*** T. F. KYCIA, LEROY T. KERTH, AND R. G. BAENDER, *University of California, Berkeley.*—A momentum-separated $K^+$-meson beam was obtained with two strong-focusing analyzing magnets. The $K^+$ mesons were identified by four scintillation counters by time of flight. Confusion with $\pi$ mesons was minimized by requiring an anticoincidence of a velocity-threshold Čerenkov counter. The $\pi$ meson and proton contamination of the identified $K^+$ mesons was estimated to be much less than 1%. From the scattering data of $K^+$ mesons on a 6-in. long liquid hydrogen target we obtained the preliminary total cross sections given in Table I. Fifteen annular

TABLE I. Total $(K1,\rho)$ cross sections.

| $K^+$ energy (lab) (Mev) | $175\pm25$ | $225\pm25$ | $275\pm25$ |
|---|---|---|---|
| Cross section (mb) | $16.4\pm1.4$ | $14.6\pm1.2$ | $15.6\pm1.4$ |

scintillation counters behind the target indicated the angle of the scattered $K^+$ meson or the recoil proton. The two kinds of particles were identified by range. Preliminary data on the angular distribution of the $K^+$ mesons indicate a slight forward peaking. The total $(K^+,n)$ cross section obtained from scattering off carbon and $CD_2$ also will be presented.

* Work done under the auspices of the U. S. Atomic Energy Commission.

**H6. Spin-Orbit Coupling in $K^+$ Meson-Proton Scattering.*** LEROY T. KERTH AND T. F. KYCIA, *University of California, Berkeley.*—An analysis similar to that used by Case and Pais[1] for nucleon-nucleon scattering has been carried out for $K^+$ mesons scattered by protons. Short-range potentials of the form $(1/x)(d/dx)(e^{-x}/x)$ for the spin-orbit potential and a central potential of the form $(1/x)e^{-x}$ were used. Experiment shows the total cross section to be rather flat with $K^+$-meson energy up to about 2 Bev.[2] The relative strengths of the central potential and the spin-orbit potential are adjusted to fit the total cross-section data. The angular distribution given by these potentials can be compared with experiment. Reasonable agreement with the preliminary data is achieved.[3]

* Work done under auspices of the U. S. Atomic Energy Commission.
[1] K. M. Case and A. Pais, Phys. Rev. **80**, 203 (1950).
[2] Caldwell, Frisch, Hill, Ritson, Schluter (private communication).
[3] Preceding abstract.

**H7. $K^+$-Meson Interactions in Nuclear Emulsion.*** D. FOURNET DAVIS, M. F. KAPLON, AND N. KWAK, *University of Rochester.*—The study of $K^+$-meson interactions in nuclear emulsion has been continued.[1] The "separated" $K^+$-meson beam produced at the Berkeley bevatron entered the stack at an energy of 250 Mev and was brought to rest in the emulsion. A track length of 77.5 meters has been scanned giving 97 inelastic events. The energy dependence of the cross section and of the ratio, charge exchange/inelastic scatter, will be discussed. The elastic scattering in the energy region 100–250 Mev will also be presented.

* This work was supported in part by the U. S. Atomic Energy Commission and by the Office of Scientific Research, Air Research, and Development Command, U. S. Air Force.
[1] D. Fournet Davis and M. F. Kaplon, Bull. Am. Phys. Soc. Ser. II, **3**, 270 (1958).

**H8. Charge Exchange of $K^+$ Mesons. I.*** MARIAN N. WHITEHEAD, ROBERT W. BIRGE, LEROY T. KERTH, AND ROBERT E. LANOU, JR., *University of California, Berkeley.*—The apparent charge exchange of $K^+$ mesons in nuclear emulsion[1,2] has been seen at energies of 50 to 300 Mev. We have previously reported[3] the charge exchange of the $K^+$ to $K_1^0$ (short-lived) observed in the propane bubble chamber. However, the corresponding observation of $K^+\rightarrow K_2^0$ (an event in which a $K^+$ disappears and no neutral decay is seen) is difficult because it involves definite identification of the $K^+$. To measure the cross section for both of these processes, a counting scheme has been devised that measures the total disappearance rate of $K^+$ in a target and the charged decay of $K_1^0$. As a calibration the mean free path for the production of $K_1^0$ and $K_2^0$ was measured, using nuclear emulsion as a target in the counter array, at 170 Mev and at 230 Mev. We find for 170 Mev $\lambda(K_1^0)=428\pm128$ cm, $\lambda(K_2^0)=475\pm50$ cm and for 230 Mev $\lambda(K_1^0)=440\pm65$ cm, $\lambda(K_2^0)=475\pm30$ cm.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Lanutti, Goldhaber, Goldhaber, Chupp, Giambuzzi, Quareni, and Wataghin, Phys. Rev. **109**, 2121 (1958).
[2] Evans, Hassan, Nagpaul, Shafi, Helmy, Mulvey, Prowse, and Stork (preprint).
[3] Whitehead, Birge, Fowler, Lanou, and Powell, Bull. Am. Phys. Soc. Ser II, **3**, 24 (1958).

**H9. Charge Exchange of $K^+$ Mesons. II.*** ROBERT E. LANOU, JR., ROBERT W. BIRGE, LEROY T. KERTH, AND MARIAN N. WHITEHEAD, *University of California, Berkeley.*—Previous experiments[1,2] to produce $K_1^0$ mesons by the charge exchange of $K^+$ mesons in complex nuclei resulted in fluxes of $K_1^0$ mesons lower than expected. One of the experiments utilized tungsten in a multiplate cloud chamber; the other utilized carbon in a propane bubble chamber. We have now (using the counter scheme mentioned in the preceding abstract) measured the cross section for the production of $K_1^0$ and $K_2^0$ for 230-Mev $K^+$ mesons incident on tungsten. Preliminary analysis of the data gives $\sigma_{K_1^0}=124\pm29$ mb, $\sigma_{K_2^0}=130\pm19$ mb. Results will also be presented on the cross sections in carbon, copper, and form a $CD_2$-$CH_2$ subtraction.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Lanou, Birge, Courant, and Whitehead, Bull. Am. Phys. Soc. Ser. II, **3**, 24 (1958).
[2] Whitehead, Birge, Fowler, Lanou, and Powell, Bull. Am. Phys. Soc. Ser. II, **3**, 24 (1958).

**H10. $K^-$ Absorption in Helium. I.*** J. LEITNER AND E. M. HARTH, *Syracuse University*, M. M. BLOCK, B. BRUCKER, I. HUGHES, T. KIKUCHI, AND C. MELTZER, *Duke University*, A. PEVSNER AND F. ANDERSON, *Johns Hopkins University*, AND H. COHN, *Oak Ridge National Laboratory.*—The Duke University liquid helium bubble chamber was exposed to a low-energy $K^-$ beam at the Berkeley Bevatron. The chamber is situated in a magnetic field of 14.3 kilogauss. In about 90 000 pictures we observed about 9000 $K^-$ mesons of which about 2500 were stopped in the chamber. The following features of the $K^-$-helium interaction are being studied: (1) the neutral to charged hyperon production ratio, (2) relative numbers of $\Lambda_0$'s produced both directly and by $\Sigma\rightarrow\Lambda_0$ conversion, (3) angular correlations in $\Lambda^0$ decay, pertinent to the question of parity conservation in $\Lambda^0$ production, (4) hyperfragment production rates. Preliminary scanning shows that $\Lambda^0$ production predominates over charged $\Sigma$ production; this is expected from the large $\Sigma-\Lambda^0$ conversion observed in $K^-$ absorption in deuterium.

* This work was supported by the U. S. Atomic Energy Commission, Office of Naval Research, and the Office of Scientific Research.

**H11. $K^-$ Absorption in Helium. II. Relative $K^-$-$\Lambda$ Parity.*** A. PEVSNER AND F. ANDERSON, *Johns Hopkins University*, M. M. BLOCK, B. BRUCKER, I. HUGHES, T. KIKUCHI, AND C. MELTZER, *Duke University*, H. COHN, *Oak Ridge National*

*Laboratory*, E. HARTH AND J. LEITNER, *Syracuse University*.—In the Duke helium bubble chamber $K^-$ exposure described above preliminary evidence has been found for the existence of a ${}_\Lambda He^4$ hyperfragment. The interpretation of the event as $K^-+He^4 \rightarrow {}_\Lambda He^4+\pi^-$ is based on the observation of a stopping $K^-$ meson from which emerges a $\pi^-$ of momentum $252\pm12$ Mev/c collinear ($\pm2°$) with a stub of range $0.62\pm0.08$ cm. Kinematic calculations lead one to expect a $\pi$ momentum of 257 Mev/c and a stub of range 0.60 cm. Details of the measurement will be discussed as well as some low probability sources of ambiguity. The existence of the reaction $K^-+He^4 \rightarrow {}_\Lambda He^4+\pi^-$ has bearing on the relative $K^-\text{-}\Lambda^0$ parity if it is assumed that parity is conserved in the reaction, that all particles in the reaction have spin 0, and that no bound excited states of the ${}_\Lambda He^4$ exist. Under these assumptions existence of the above reaction would lead to the assignment of negative relative parity of the $K^-$ and $\Lambda^0$. The foregoing assumptions and conclusions will be discussed more fully.

* This work was supported by the U. S. Atomic Energy Commission, Office of Naval Research, and the Office of Scientific Research.

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THURSDAY MORNING AT 9:45

Grand Ballroom

(M. B. GOTTLIEB presiding)

## *Symposium on Applied Plasma Physics*

**HA1. Review of Project Sherwood.** EDWARD TELLER, *University of California*. (30 min.)

**HA2. Building Plasma by High-Energy Injection.** P. R. BELL, *Oak Ridge National Laboratory*. (30 min.)

**HA3. Production of High-Temperature Plasmas and Experimental Studies of Some of Their Properties.** KEITH BOYER, *Los Alamos Scientific Laboratory*. (30 min.)

**HA4. Ion Cyclotron Resonance in a Plasma.** T. H. STIX, *Princeton University*. (30 min.)

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THURSDAY MORNING AT 9:45

Governor Clinton Hotel

(W. L. BROWN presiding)

## *Semiconductors II*

**J1. Weak-Field Magnetoresistance for the ⟨110⟩ Many-Valley Model with General Ellipsoids.** R. S. ALLGAIER, *U. S. Naval Ordnance Laboratory*.—In the case of the many-valley model having energy ellipsoids along the ⟨110⟩ directions in $k$ space, cubic symmetry does not require ellipsoids of revolution, but only a certain orientation of the principal axes of an ellipsoid. For example, the principal-axis directions of the ellipsoid in the first quadrant of the $x$-$y$ plane are [110], [1$\bar{1}$0], and [001]. We have extended the magnetoresistance calculations of Abeles and Meiboom, and Shibuya, to this situation, obtaining the three weak-field magnetoresistance coefficients $b$, $c$, and $d$ in terms of the two mass ratios $K$ and $L$ needed to describe the relative size of the three masses. We find that along different lines in the $K$-$L$ plane each of the symmetry conditions $b+c-d=0$, $b+c=0$, or $b+c+d=0$, which are appropriate for the ⟨110⟩, ⟨111⟩, and ⟨100⟩ ellipsoid-of-revolution models, respectively, may be satisfied for the more general ⟨110⟩ model. Further details of the generalization will be presented.

**J2. Energy Levels of Conduction Electrons in a Magnetic Field Application to $n$ InSb.** Y. YAFET, *Westinghouse Research Laboratories*.—In the approximation of spherical bands, a selection rule of the interband matrix element of the velocity between Luttinger-Kohn (L.K.) states makes it possible to obtain the eigenfunctions and energy levels of conduction electrons in a magnetic field. Neglecting level broadening due to the lattice periodicity, the levels are obtained by solving a secular determinant whose order equals the number of L.K. states retained in the formulation of the eigenvalue problem for the band of interest. Inclusion of spin-orbit coupling gives the $g$ factor as function of position in the band. For purposes of calculating the nonoscillatory part of the susceptibility, small departures of the band from sphericity may be treated by perturbation theory. This method is used in a calculation of the susceptibility of conduction electrons in InSb where the band is nonparabolic. The purpose was to compare the susceptibility measurements of Bowers[1] with the band structure proposed by E. O. Kane. Good agreement is found between the two. The method should also be useful for metals with nearly spherical bands, such as the alkalis.

[1] R. Bowers, Bull. Am. Phys. Soc. Ser. II **3**, 120, (1958).

**J3. Semiconductor Metal Barriers in a Three-Dimensional Presentation.** H. W. JADERHOLM, *Candian Marconi Company* (introduced by D. A. Anderson).—In the Schottky barrier diagram potential is shown as a function of the distance, with the carrier population as an auxiliary view. New diagrams of a metal semiconductor barrier showing potential and charge have been developed from Shockley's theory. Depletion and enrichment regions are quantitatively illustrated and the static barrier resistance and capacitance can be found directly from the coordinates of the operating point. The ac capacitance is found from the slope of the operating line, and the $Q$ factor is the ratio of two areas shown on the diagram, one representing the energy stored during one cycle and the other the energy lost. When the distance from the interface is added a three-dimensional structure emerges from which many important formulas can be found by inspection. Slides and three-dimensional models will be available to illustrate these concepts and to show what uses can be made of them.

**J4. Recombination in Germanium with Nickel Impurity.** G. K. WERTHEIM, *Bell Telephone Laboratories.*—The recombination properties of nickel in germanium have been reinvestigated in order to reconcile the various divergent results in the literature. Crystals, both *n* and *p* type, into which nickel was introduced by diffusion at temperatures between 500 and 800°C as well as crystals grown from a melt containing nickel and either gallium or arsenic have been studied using the PME effect, the Hall effect, conductivity, and the decay of bombardment-induced conductivity. In *n*-type crystals recombination proceeds via the upper nickel acceptor level; in *p* type, at low temperature, via the lower acceptor level. As the temperature is *raised* and the Fermi level approaches the lower level the lifetime *decreases*. This is explained by the appearance of the upper level with a cross section for electron capture larger than that of the lower level, as the latter is populated by electrons. In every case electron capture is the rate-limiting process. The capture constants of both levels are independent of temperature in the ranges studied. The results indicate that (1) the capture cross section of the upper level is about six times that of the lower one, (2) that both of the levels belong to an individual atom and (3) that a level corresponding to the transition between a singly and doubly negative state is not necessarily a hole trap.

**J5. Nitrogen Content and Lattice Constant of Common Type I Diamonds.** W. KAISER, W. L. BOND, AND M. TANENBAUM, *Bell Telephone Laboratories.*—Diamonds with absorption bands between 6 and 13 $\mu$ are commonly called type I diamonds, and specimens without absorption in this wavelength region are called type II.[1] A satisfying answer as to the origin of these absorption bands has not yet been given. We have found that diamonds contain considerable amounts of gases, predominantly nitrogen. The absorption band at 7.8 $\mu$ increases with increasing nitrogen content. A nitrogen concentration of 0.1% was measured in a stone with an absorption coefficient $\alpha=40$ cm$^{-1}$ at 7.8 $\mu$. Also the lattice constant of diamonds increases with the infrared absorption at 7.8 $\mu$. The lattice constant of type II diamonds is $a=3.56686\pm2\times10^{-5}$ A. For strong type I diamonds with $\alpha=60$ cm$^{-1}$ at 7.8 $\mu$ the relative increase in lattice constant $\Delta a/a$ is as high as $10^{-4}$. Possible lattice sites occupied by nitrogen and the implication of our findings on other physical properties of diamond will be discussed.

[1] Robertson, Fox, and Martin, Phil. Trans. Roy. Soc. (London) Ser. A, **232**, 463 (1934); Sutherland, Backwell, and Simeral, Nature **174**, 901 (1954); R. J. Collins and H. Y. Fan, Phys. Rev. **93**, 674 (1954); M. Lax and E. Burstein, Phys. Rev. **97**, 39 (1955).

**J6. Electrical Measurements on Cleaned (111) and (100) Germanium Surfaces.*** R. FORMAN, *National Carbon Research Laboratories.*—Field effect and conductivity measurements have been made on cleaned (111) and (100) surfaces of germanium. The surfaces were cleaned using an argon sputtering technique. Measurements were made at ultrahigh vacuum and with ambients of oxygen and wet nitrogen. Results on the (111) surface were different from those obtained on the (100) surfaces and these differences will be discussed. In particular, the measured field effect mobility for a (111) surface rose to a value as high as 1000 cm$^2$/volt-sec when the cleaned surface was exposed to an oxygen ambient. The field effect mobility for cleaned surfaces was on the order of 100–200 cm$^2$/volt-sec, if the surfaces were heated to 650–700°C after argon bombardment and then further annealed at approximately 500°C.

* Abstract of oral paper to be presented at the American Physical Society Meeting in New York, January, 1959.

**J7. Thermal Oscillations in *n* Germanium.** S. H. KOENIG AND R. D. BROWN, *IBM Watson Laboratory.*—It has been known for some time that an apparent negative resistance often occurs in bulk germanium at the onset of low-temperature breakdown. We have shown this negative resistance to be associated, in *n* germanium, with a thermal relaxation oscillation of the sample at a rate determined mainly by the parameters of the associated circuitry. The amplitude of the thermal oscillation may be as great as 2°K (from 4.2°K to 6.2°K). Accompanying this is an electrical oscillation whose magnitude is determined by the decrease in breakdown field over this temperature range, which in the case of ~3Ω cm Sb doped Ge with ~5–10% compensation is ~1 volt/cm. The observed negative resistance comes from measuring the time average field across the sample when it is oscillating. We have investigated the amplitude of the electrical oscillations as a function of equilibrium lattice temperature and sample purity. The results can all be understood in terms of the known criterion for breakdown,[1] and its dependence on lattice temperature and impurity concentration.

[1] S. H. Koenig, Phys. Rev. **110**, 986 (1958).

**J8. Optical Constants of Germanium and Silicon in the Region 1 to 10 ev.** H. R. PHILIPP AND E. A. TAFT, *General Electric Research Laboratory.*—The reflectance, $|r(\lambda)|^2$, of of single-crystal germanium and silicon was measured in the range 0.6 to 11.3 ev. The Kramers-Kronig relation was applied to this spectrum and the real and imaginary parts of the complex index of refraction, $n$ and $k$, were determined. The results for germanium agree with the recent measurements of Archer[1] and extend his values beyond 3.5 ev. Pronounced structure is observed in both germanium and silicon in the vicinity of 4.5 ev. The extinction coefficient rises to a peak near this energy. At 80°K, the peak sharpens and shifts toward higher energy. The strength of this absorption should be useful in testing and refining band structure calculations. Based on the Frohlick-Pelyer criterion,[2] which is applicable to nonmetals, no evidence for plasma oscillations was found. Discrete energy losses have been observed at higher energy, and it would be of considerable interest to extend the present data to that range.

[1] R. J. Archer, Phys. Rev. **110**, 354 (1958).
[2] H. Frohlick and H. Pelyer, Proc. Phys. Soc. (London) **68A**, 525 (1955).

**J9. Infrared Absorption of Oxygen in Silicon.** H. J. HROSTOWSKI AND W. KAISER, *Bell Telephone Laboratories,* AND B. J. ALDER, *University of California, Berkeley.*—Infrared spectra of silicon containing oxygen enriched with 57% $O^{18}$ and 1.5% $O^{17}$ have been obtained for temperatures between 300°K and 4.2°K. The results give additional information about the isotopic shifts reported earlier[1] and are consistent with the proposed nonlinear $Si_2O$ configuration.[2] The absorption near 1100 cm$^{-1}$ shows the same unusual temperature dependent fine structure for $O^{16}$, $O^{17}$, and $O^{18}$. However, for silicon alloyed with about 2% germanium the temperature dependence of the fine structure is radically altered. No fine structure is resolved above 78°K, but three absorption maxima are observed at 4.2°K. Assuming random substitution for silicon atoms by germanium, only 4% of the oxygen atoms exist in SiO Ge units. Since these absorb at a lower frequency, they have little effect on the $Si_2O$ absorption. However, a large fraction of the oxygen atoms have environments which differ because of germanium neighbors in the silicon lattice. These results show that the behavior of the 1100 cm$^{-1}$ band is influenced primarily by the environment and suggest that the fine structure arises from restricted internal rotation or tunneling of the oxygen atom.

[1] H. J. Hrostowski and R. H. Kaiser, Phys. Rev. **107**, 966 (1957).
[2] Kaiser, Keck, and Lange, Phys. Rev. **101**, 1264 (1956).

**J10. Electron Diffusion in High-Purity *p*-Type Silicon.** M. GREEN, I. N. GREENBERG, AND J. MANDELKORN, *U. S. Army Signal Research and Development Laboratory.*—Metal contacts to high-purity *p*-type silicon (*ca* 2000 ohm/cm) are all more or less rectifying at room temperature. Silver bonded, gold sputtered, and indium plated contacts give peak photo-

voltages of the order of 100 to 150 mv when irradiated at the contact with a high-intensity light flash. As the position of the light image (focused as a narrow line or point) is moved away from the junction there is a delay in the time at which the peak photovoltage occurs. This delay is related to the ambipolar diffusion constant $D$. If $x^2$ ($x$ is distance from light image to junction) is plotted against the time at which the maximum in the diffusion current occurs, the initial slope gives a value proportional to $D$; the proportionality factor being between 10 and 20 depending on conditions. For steady-state illumination, one-dimensional geometry, and sample long compared to $(D\tau)^{\frac{1}{2}}$, theory predicts that the photocurrent $i_p$ is given by $i_p = i_0 E\mu_n \exp[-x/(D\tau)^{\frac{1}{2}}][E\mu_n + (D/\tau)^{\frac{1}{2}}]$, where $i_0$ is the total photoinjected electron current, $E$ is the field at the junction (assumed linear), $\mu_n$ electron drift mobility, and $\tau$ effective sample lifetime. Illumination at the center of the specimen, with weak dc field applied, gives a change in conductance proportional to $i_0\tau$. This permits the determination of $E$, $i_0$, and the $\tau$ of the specimen.

**J11. New Cyclotron Resonance Effects in Ge and Evidence for Carriers with Negative Mass.** GEORGE C. DOUSMANIS, ROBERT C. DUNCAN, JR., JOHN J. THOMAS, AND ROSCOE C. WILLIAMS, *RCA Laboratories*.—Cyclotron resonance experiments, suggested earlier[1] for the detection of negative-mass carriers, have been carried out with Ge crystals at 4°K. Use of circularly polarized microwaves has revealed a new spectrum of heavy holes which, from the tests tried so far, may be assigned to carriers of negative mass. This spectrum is of the emission type; it appears as a "dip" in the background absorption, rather than as an absorption peak. The value for the effective mass is $-(0.22\pm0.06)m_0$, in reasonable agreement with calculation. A smaller dip has also been observed at $m^* \sim -0.48m_0$. The magnitude of the main dip is between 2 and 12% of the usual heavy hole resonance. This is comparable to the predicted value[1] of about 4% for the relative number of negative-mass heavy holes. High microwave power eliminates the effect, possibly by driving the carriers out of the negative cone regions. The magnetic field is oriented along the (100) axis. Misorientation of $H$ by about 20° out of this axis reduces the magnitude of the effect, a behavior to be expected from the small angle of the negative-mass cone. The circular polarization data cover the entire spectral region of Ge for both positive and negative values of $H$.

[1] G. C. Dousmanis, Phys. Rev. Letters 1, 55 (1958).

**J12. Carrier Density, Mobility Ratio, and Impurity Concentration in High-Resistivity $p$-Type Silicon.** C. A. KLEIN AND W. D. STRAUB, *Raytheon Manufacturing Company*.—Hall coefficient $R$ and conductivity $\sigma$ of $p$-type silicon samples having $N_A - N_D$ values ranging from less than $10^{13}$ to a few $10^{15}$ cm$^{-3}$ were carefully measured as a function of temperature between 25 and 400°K. A constant magnetic induction of 2420 gauss was used, and the applied electric fields were not allowed to exceed 1 volt/cm. The Hall mobilities $R\sigma$ at 300°K were found to lie between 340 and 360 cm$^2$/volt-sec indicating that even for the purest samples the mobility ratio $\mu_H/\mu$ has a value less than unity at room temperature. For a typical $N_A - N_D = 2.5\times10^{14}$ cm$^{-3}$ sample $\mu_H/\mu \sim 0.71$ at 300°K and follows a $T^{-0.31}$ law at least between 140 and 400°K. At lower temperatures, where galvanomagnetic fine structure effects should occur (mobilities $R\sigma$ of over $10^5$ cm$^2$/volt-sec were observed), the Hall coefficient factor $r$ was obtained by an analysis of the $1/Re$ data based on theoretical considerations of the carrier density in $p$-type silicon. The results are consistent with predictions by Beer and Willardson,[1] and apparently lead to reasonable determinations of the total impurity concentration in our specimens.

[1] A. C. Beer and R. K. Willardson, Phys. Rev. 110, 1286 (1958).

**J13. Collision Ionization in $n$-Indium Arsenide.** M. C. STEELE, *RCA Laboratories*.—Pulsed measurements on several different polycrystalline $n$-InAs samples have shown that electron-hole pairs are created by collision ionization when the applied electric field exceeds a threshold of about 600 volts/cm. Beyond the threshold the current density increases very rapidly for further small changes in electric field. Simultaneous Hall measurements have shown that the carrier concentration increases sharply beyond the threshold. All the crystals used were compensated and had total impurity concentrations of about $10^{17}$/cc. A typical sample at 300°K had an initial $n \sim 5\times10^{15}$/cc and an electron mobility of about 9000 cm$^2$/volt-sec. After creation of electron-hole pairs the carrier concentrations was increased to $4\times10^{16}$/cc. At the latter value the current density was $5\times10^4$ amps/cm$^2$ and the electric field was $10^3$ volts/cm. Data were taken at 300°K, 232°K, and 77°K. There were no significant changes in the characteristics of the ionization over this temperature range. At 77°K the drift velocity, defined as the product of the Hall coefficient (measured at 3500 oersteds) and the current density, showed saturation at a value of $1.5\times10^7$ cm/sec for electric fields beyond the threshold.

**J14. Trapping Effects in Lifetimes Measurements by the PC-PEM Ratio Method.** A. AMITH, *RCA Laboratories*.—A detailed analysis is carried out on the influence of "centers" in the forbidden gap upon the value of the carrier lifetime as determined by the ratio of the photoelectromagnetic and photoconductive effects. It is shown how the action of the centers as traps for either type of carriers or as generation or recombination sites depends upon their own parameters as well as the statistics of the bulk carriers. The analysis is then specialized to small signals in extrinsic semiconductors wherein the light is very strongly absorbed. It is shown that the sign of the error in the value of the lifetime as well as its dependence upon the extent of trapping is different for the cases of majority and minority carrier trapping. In the former case, the error is limited by the mobility ratio, whereas in the latter the error keeps increasing with increased trapping. Under the stated conditions, the PEM is not affected by the traps, and their influence in the determination of the lifetime comes through the photoconductivity. Temperature dependence of PEM and PC in GaAs will be explained in this manner.

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THURSDAY MORNING AT 9:45

Empire Room

(L. H. THOMAS presiding)

## *Theoretical Physics III: Largely Quantum Mechanics and Field Theory*

**JA1. New Scattering Approximation.** J. MAYO GREENBERG, *Rensselaer Polytechnic Institute*.—A scattering approximation has been developed which, in the high-energy region, is of comparable simplicity to the Born and soft sphere approximations[1] but which is a considerable improvement over these. The method consists in choosing a trial function with a

number of parameters $\alpha_1, \cdots, \alpha_n$, inserting this in the scattering integral equation, and then determining the parameters by requiring that the integral equation and a sufficient number of derivatives be satisfied at either the origin or other regions of space. The trial function is then used to give the scattering amplitude. It can be shown that this method leads to the soft sphere approximation as applied to a square well potential if one limits the form of the trial function to be a forward and plane wave. The convergence of the procedure has been numerically demonstrated by comparing the results of using three plane wave trial functions with those using two plane wave trial functions, where the parameters are the amplitudes of the waves. The analytical simplicity of the method leads to the possibility of considering problems of increased complexity.

[1] E. W. Montroll and J. M. Greenberg, Phys. Rev. **86**, 889 (1952).

**JA2. Analytical Solutions of Potential Scattering in a New Approximation.** W. B. WRIGHT, *Knolls Atomic Power Laboratory*,* J. MAYO GREENBERG, *Rensselaer Polytechnic Institute*.—A simple analytical method for handling the problem of potential scattering has been developed. The solution of Schroedinger's equation is taken to be a finite sum of plane waves, $\psi_{\text{trial}} = \sum_n a_n \exp\{i\mathbf{k}_n \cdot \mathbf{r}\}$, where the wave numbers are considered known and the coefficients are evaluated taking $n$ radial derivatives of the integral form of the Schroedinger equation at the origin. The method is applied to a number of potential wells and the results compared with digital computer calculations. It is of particular note that the optical theorem gives nearly the correct total cross section in a number of cases indicating that this simple approach specifies the phase of the wave function reasonably well.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

**JA3. Physical Limitations on Adiabatic Switching in Scattering Theory.*** B. A. LIPPMANN, *University of California, Livermore*.—Using wave packets (adiabatic switching) in scattering theory, we encounter three characteristic energies; $\Delta E_s$, the level-spacing associated with the finite volume of quantization (source modes), $\Delta E_d$, the energy resolution of the measuring equipment (detector modes), and $\epsilon$, the energy width of the wave packet. Physically, we assume; (a) the particle is free before and after the scattering, and (b) the phase of the (asymptotic) scattered wave, relative to that of the incident wave, can be measured. This means that (a) the particle can be localized outside the region of interaction, and (b) the incident and scattered waves are coherent at the detector; i.e., $\Delta E_s \ll \epsilon \ll \Delta E_d$. Thus, $\epsilon$ is vanishingly small in the detector region. If $\epsilon$ vanished everywhere, a lack of uniqueness in exchange scattering could be inferred, for, in these collisions, as $\epsilon$ vanishes so does the contribution of the incident wave.[1] However, as emphasized here (and earlier),[1] $\epsilon$ is not negligible for the source modes, hence the uniqueness of the wave function is not impaired.

* Work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] B. A. Lippmann, Phys. Rev. **102**, 264 (1956).

**JA4. Dirac-Like Wave Equations for Particles of Nonzero Rest Mass and Their Quantization.** J. S. LOMONT, *IBM Research Center*, AND H. E. MOSES, *New York University*.—Dirac-like equations of the form $(\gamma^\mu \nabla_\mu + m)\psi = 0$, where the $\gamma^\mu$ matrices satisfy the usual Dirac rules, are set up for all nonzero spins. In contrast to the usual techniques in which higher rank four-spinors are used, we employ a technique analagous to that used for massless particles.[1] The irreducible representations of the Lie algebra generated by the $\gamma^\mu$ matrices and the infinitesmal transformations of the homogeneous Lorentz group are found. For each such representation a wave equation is obtained. In general such equations represent multiple-spin particles. However, by setting a number of components of $\psi$ identically equal to zero, single-spin equations are obtained. Electromagnetic interactions, definitions of currents, and quantization will also be discussed.

[1] J. S. Lomont, Phys. Rev. **111**, 1710 (1958).

**JA5. Relation of the Vector Meson Equation and the Dirac-Like Equation of Spin 1.** H. E. MOSES, *New York University*, AND J. S. LOMONT, *IBM Research Center*.—The equation for spin 1 of the previous abstract contains as special cases both the neutral and charged vector meson fields. Four of the components of the wave function are identified with the vector potential and the remaining components are the field functions.

**JA6. Scattering of Vector Waves.*** W. M. BROWN† AND D. S. SAXON, *University of California, Los Angeles*.—A recently proposed formulation for the scattering of scalar waves[1] is extended to the problem of vector-wave scattering. Using a suitable tensor Green's function, an integral representation of the vector wave function is obtained which is similar in form to the scalar result except for an additional characteristic "mixing" integral. For index of refraction, $n$, nearly unity, the formulation parallels that of the high-energy scalar problem. Under this condition, successive iteration yields a rapidly converging series for both wave function and scattering amplitude. It follows, for slowly varying $n$, that finding the vector scattering amplitude is reduced to a scalar problem. In the close-in region, all the components of an improved wave function are calculated. It is shown that in this region there exists a component polarized along the incident direction which is an order of magnitude larger than the component polarized perpendicular to the plane of incidence. A consequence of this result is a significant polarization of the 90° scattering in the plane of incidence. The amplitude of this effect is calculated explicitly for scattering from a dielectric sphere.

* Supported in part by the National Science Foundation.
† Now at the RAND Corporation, Los Angeles.
[1] D. S. Saxon and L. I. Schiff, Nuovo cimento **6**, 614 (1957).

**JA7. Solutions of the Dirac Simple Harmonic Oscillator Model.** R. E. NORTON AND W. K. R. WATSON, *California Institute of Technology*.—The model proposed by Dirac[1] characterized by the Hamiltonian

$$H = \frac{1}{2m_0}\left[\mathbf{p}(t) - e\int \rho(x')\mathbf{A}(x',t)d^3x'\right]^2 + \frac{1}{2}\int\left[(\nabla \mathbf{A}(x',t))^2 + (\pi(x',t))^2\right]d^3x' + \frac{1}{2}K\mathbf{r}^2(t)$$

has been solved exactly. The equations of motion are derived from the usual commutation rules, and the mass correction expressed in terms of the cutoff is $\delta m = 4\pi e^2 \int \rho^2(k)dk$. If the cutoff is chosen such that $\delta m < m_R$ the theory is consistent. However if we choose $\rho(k)$ such that $\delta m > m_R$ (i.e., $m_0 < 0$), we find an additional pole occurring in the upper half plane of the scattering amplitude, corresponding to lack of causality, and we find that the usual equal time commutators of the field operators possess extra terms. This latter manifestation of lack of causality cannot be avoided if we insist upon a unitary $S$ matrix and do not include the analogue of the classical "run-away" solutions of Dirac.

[1] P. A. M. Dirac, Proc. Roy. Soc. (London) **167**, 148 (1938).

**JA8. Consistent Acausal Solution of the Dirac Model.** W. K. R. WATSON AND R. E. NORTON, *California Institute of Technology*.—It has been shown[1] that in the event of the mass correction being greater than the renormalized mass, it is impossible to obtain consistent commutation rules for the

Dirac model if we neglect the "run-away" solutions. It will be illustrated that the inclusion of these "run-away" solutions can give consistency, but in order to quantize these peculiar states the Hamiltonian has to be regarded as non-Hermitian, and gives rise to imaginary eigenvalues which cannot be interpreted physically. In order to avoid these difficulties it is convenient to use the acausal commutation rules to derive the equations of motion which possess the usual solutions but not the run-away solutions. A recalculation of the commutation relations from these equations of motion will then yield the same set of acausal commutation rules that were used to derive the equations of motion, thus guaranteeing the consistency of the theory.

[1] R. E. Norton and W. K. R. Watson, Bull. Am. Phys. Soc. Ser. II, 1, 29 (1959).

**JA9. Models in Abstract Field Theories.** M. DRESDEN, *Northwestern University.*—There are now several versions of abstract quantum field theories,[1] which are already renormalized and which presumably give unambiguous, finite answers to physical questions. Such theories are described by the character of—and the relations between—the vacuum expectation values of ordered products (Wightman functions). It is not known to what extent the usual quantized field theories are contained in this general framework. It is interesting to investigate just how the coupling terms in the conventional description occur in the abstract theory. An initial attempt has been made, by studying some exactly soluble models. For these models the Wightman functions can be obtained, and one may verify the requirements which the abstract theory imposes on them. For the Lee model one can only verify these relations if the coupling constant is less than a critical value. A similar calculation can be made for the Thirring model.[2] The physically more interesting question, what conditions must be added to those of the abstract theory to lead to a particular model, may be studied using these results.

[1] Lehman, Symanzik, and Zimmerman, Nuovo cimento 1, 205 (1955).
[2] Thirring, Ann. Phys. 3, 191 (1958).

**JA10. Von Neumann's Infinite Direct Product Spaces and Quantum Field Theory.** M. SCHWARTZ, *University of Minnesota.*—The scalar field interacting with fixed heavy nucleons, which has previously been discussed by Van Hove[1] and Miyatake,[2] will be rediscussed in relation to von Neumann's infinite direct product spaces. It will be argued that the above authors[1,2] treat normalization in Hilbert functional space and Hilbert vector space inconsistently. The total Hamiltonian eigenstates may be obtained from the free field Hamiltonian eigenstates by a unitary transformation which is defined over a nonseparable complete direct product space. One must treat transformation coefficients formally so that norms of eigenstates may be calculated in Hilbert vector space in the same sense that infinite products of Hermite function normalization factors are treated formally in calculating norms of eigenstates in Hilbert functional space. From the above point of view, one would not say that total Hamiltonian eigenstates are orthogonal to free field Hamiltonian eigenstates. Extrapolating to field theory in general, one might say that amplitudes should always be treated formally, whereas it is only probabilities which should be treated numerically. Several other simple field theoretical models will also be mentioned in connection with von Neuman's theory.

[1] L. Van Hove, Physica 18, 145 (1952).
[2] O. Miyatake, J. Inst. Polytech., Osaka City Univ. Ser. A 2, 89 (1951); 3, 145 (1952).

**JA11. Four-Dimensional Lie Ring and Elementary Particle Equations.** T. AHRENS, *Georgia Institute of Technology* (introduced by C. H. Braden).—It is well to investigate elementary particle equations as to their manifestly covariant origin rather than merely demonstrate *a posteriori* what seem to be their pertinent transformation properties. Important facets may then develop which otherwise might remain hidden. It is known that the representations of the proper Lorentz and 4-dimensional rotation groups can be generated by the "4-dimensional Lie ring," which is characterized by two 3-vectors, $K$ and $H$, satisfying the commutation relations $K\times K=iK$, $H\times H=iH$ and $K\times H=0$. In $c$-number theory a state $\psi$ will then transform, e.g., according to $\exp(i<I>\cdot a\alpha)$ $\exp(i<J>\cdot b\beta)\psi$, with $a$ and $b$ the unit vectors along rotational and "translational" axes, respectively, and $I=K+H$, $J=K-H$. In the case of the proper Lorentz group $\alpha$ is real and $\beta$ imaginary, while both are real when considering $\mathfrak{R}_4$. The properties of the lepton equations with respect to $\mathfrak{L}$ and $\mathfrak{R}_4$ have been investigated. One result, e.g., is the establishment of a correspondence between proper Lorentz transformations and "complex rotations" in 3 space.

**JA12. Group Representations with an Invariant and Indefinite Metric.** A. O. BARUT, *Syracuse University.*—An indefinite metric in Hilbert Space has been introduced in several instances notable in connection with the quantization of the electromagnetic field, with the relativistic single particle equations, with the elimination of some of the divergence difficulties in field theories, and with the nonlinear spinor equations. A group theoretical approach to these problems will be formulated. We discuss the irreducible representations of the groups of transformations, in particular that of the Lorentz group, in a space with an indefinite metric. Importance is given to the invariance of the indefinite quadratic form to ensure the relativistic invariance of the above-mentioned theories.

**JA13. Adiabatic Invariance of Action.*** E. GERJUOY, *General Dynamics Corporation.*—The time dependence of the action $J=2\pi E/\omega$ has been examined for the case of a harmonic oscillator with circular frequency $\omega$ an arbitrary function of time. By immediately transforming to angle and action variables, previously reported results[1-3] are derived simply, and some extensions are found. In particular it is rigorously true that at time $t_f$ $<J_f^{-1}>=\int dw_i J_f^{-1}=J_i^{-1}$ for a set of particles which at time $t_i$ have the same initial action $J_i$ and are uniformly distributed in angle $w_i$, i.e., the average reciprocal action is invariant for the set. Transforming to angle and action variables is convenient also for other perturbations of the harmonic oscillator, e.g., the center of force moves with arbitrary velocity, as well as for other one-dimensional periodic systems. Although other systems are not as simple as the harmonic oscillator, it seems generally true that the action is invariant "to all orders" when all time derivatives of the perturbation are continuous, and vanish at initial and final times. Some implications for the invariance of the magnetic moment $\mu\cong\frac{1}{2}mv^2/B$ of a charged particle in a magnetic field $B$ will be discussed.

* This work was done under a contract between General Atomic and the Texas Atomic Energy Research Foundation.
[1] F. Hertweck and A. Schluter, Z. Naturforsch. 12A, 844 (1957).
[2] S. Chandrasekhar, in R. K. M. Landshoff, *The Plasma in a Magnetic Field* (Stanford University Press, Stanford University, California, 1958), p. 6.

**JA14. On the Possible Use of Nonsingle-Valued Wave Functions in Quantum Mechanics.** DAVE PANDRES, JR., *The Ohio Oil Company.*—It is proposed that nonsingle-valued solutions $\psi_i$ be admitted for the Schrödinger equation provided that $\psi_i^*\psi_j$ is single-valued for all $i$, $j$. This eliminates those solutions to which Pauli[1] objects and is necessary and sufficient to insure that the average value of an arbitrary observable is single-valued. Bohm[2] notes that this is all that one can logically require. In order to obtain a unique family of solu-

tions, it is postulated that nature selects the admissible family with lowest ground-state energy. This is not, in general, the family of single-valued functions, so experimentally detectable differences exist between this and the usual theory. However, for a particle moving in a potential field, single-valued functions are obtained if some component of angular momentum is a constant of the motion. Finally, and perhaps most important, when nonsingle-valued solutions are admitted, one obtains nondegenerate states for which the parity eigenvalue is a complex number of unit modulus.

[1] W. Pauli, *Die allgemeinen Prinzipien der Wellenmechanik*, Handbuch der Physik XXIV (Springer, Berlin, 1933), second edition, Pt. I, Chap. 2, p. 126.
[2] D. Bohm, *Quantum Theory* (Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1951), p. 389.

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## THURSDAY MORNING AT 10:00

## Panel Room

## (J. A. HARVEY presiding)

## *Fission; Neutrons*

**K1. Subthreshold Fission—$NP^{237}$ and $AM^{241}$.** B. R. LEONARD, JR., AND E. J. SEPPI,* *General Electric Company.*—The fission cross sections of $Np^{237}$ and $Am^{241}$ have been measured over the neutron energy interval of 0.1 ev to 5 ev using a crystal spectrometer. No resonance structure was observed above 1.5 ev because of the poor resolution used. Breit Wigner resonance parameters have been obtained from good resolution measurements of the 0.31-, 0.58-, and 1.27-ev fission resonances in $Am^{241}$. These resonances contribute about 2.4 barns to the 2200-m/sec fission cross section which is consistent with the reported pile neutron fission cross-section value of 3.1 barns. Fission widths of the observed resonances have been calculated using published total cross-section resonance parameters. The average fission width obtained is near the maximum expected theoretically from the fast neutron fission threshold energy. Resonances have been observed in $Np^{237}$ fission at 0.49 ev and with poor resolution at 1.32 and 1.47 ev. The inferred fission widths yield an average width an order of magnitude less than the theoretically expected minimum value. The 2200-m/sec fission cross-section value obtained by a $1/v$ extrapolation of the lowest energy data is 16 mb in agreement with the reported pile neutron value of 19 mb.

* Present address: California Institute of Technology.

**K2. Angular Distribution and Energy Spectrum of Prompt Neutrons Resulting from the Spontaneous Fission of $Cf^{252}$.*** A. SMITH, P. FIELDS, AND R. SJOBLOM, *Argonne National Laboratory.*—The laboratory energy spectrum of the prompt fission neutrons emitted from the spontaneous fission of $Cf^{252}$ is measured as a function of the angle between the directions of motion of the parent fragment and the emitted neutron. It is shown that the experimental results are in agreement with the following assumptions: (a) isotropic neutron emission in the center of mass system of each fragment; (b) identical center of mass neutron emission spectra from both the light and heavy fragments. The results indicate that fission neutron emission from the light fragment is 1.25 times more probable than from the heavy.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**K3. Anisotropy of Fragments from $U^{233}$ and $Pu^{239}$ Fission.*** L. BLUMBERG, J. BAHCALL,† D. GARRETT, AND R. B. LEACHMAN, *Los Alamos Scientific Laboratory.*—Angular distributions of fragments from neutron-induced $U^{233}$ and $Pu^{239}$ fission were measured by gross beta counting of catchers at 0°, 22.5°, 45°, 67.5°, and 90°. The distributions are observed to be peaked forward at all energies studied. The ratio $\sigma(0°)/\sigma(90°)$ for $Pu^{239}$ exhibits an increase from $1.09\pm0.02$ at 2.6 Mev neutron energy to $1.22\pm0.02$ at 7 Mev and a second step of $1.09\pm0.03$ at 11.1 Mev to $1.17\pm0.02$ at 14.1 Mev. A similar increase in anisotropy is observed for $U^{233}$ with corresponding $\sigma(0°)/\sigma(90°)$ values of $1.10\pm0.02$, $1.32\pm0.02$, $1.18\pm0.02$, and $1.28\pm0.02$. This steplike dependence on energy has previously been apparent only for even-even target nuclei.[1] The smaller magnitude of the first step in anisotropy for these odd-A targets is explained by Griffin[2] on the basis of the Bohr theory. As predicted by this theory, the anisotropy observed for $Pu^{239}$ (spin $=\frac{1}{2}$) below 2.6 Mev is greater than for $U^{233}$ (spin $=\frac{5}{2}$).

* Work performed under auspices of the U. S. Atomic Energy Commission.
† Present address: Harvard University.
[1] R. L. Henkel and J. E. Brolley, Jr., Phys. Rev. **103**, 1292 (1956).
[2] J. J. Griffin, Bull. Am. Phys. Soc. Ser. II, **3**, 337 (1958).

**K4. Delayed Gammas from Fission of $Th^{232}$, $U^{235}$, $U^{238}$, and $Pu^{239}$.*** PHILIP C. FISHER, MARTIN P. KELLOGG, PHILIP G. KOONTZ, AND LEON B. ENGLE, *Los Alamos Scientific Laboratory.*—Energy distributions of emitted gammas have been obtained for different time intervals after effectively instantaneous fast (~ fission spectrum) neutron-induced fission. A 4-×4-in. NaI crystal was employed to detect gammas having energies between 0.15 Mev and 6.5 Mev, the pulses from these gammas being recorded with the aid of a 100-channel pulse height analyzer for several time intervals between 1 sec and 45 sec after fission. Two time delay analyzers were used to follow the decay of the delayed gammas from 0.3 sec to 300 sec after fission. Preliminary results indicative of roughly similarly shaped energy distributions for a given time interval for the different fissionable isotopes will be discussed. Data on the relative number of delayed gammas emitted per atom fissioned for the different isotopes will be presented and compared to the relative number of delayed neutrons emitted per atom fissioned.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**K5. Mode of Neutron-Induced $U^{235}$ Fission at Individual Resonances in the Epithermal Energy Region.*** G. A. COWAN AND A. TURKEVICH, *Los Alamos Scientific Laboratory.*—Radiochemical measurements relating to the mode of neutron-induced $U^{235}$ fission in the energy region 9 ev to 500 ev have been made by the Los Alamos Radiochemistry Group and assisting sections of the Los Alamos Scientific Laboratory.[1] The neutron sources used were moderating radiators exposed to field test nuclear explosions at Eniwetok and Nevada. Fluxes of the order of $10^{10}$ neutrons/cm²-ev were obtained in the energy region covered on a rotating wheel with a $U^{235}$ rim. Good energy resolution was achieved by time of flight over path lengths of $1.5\times10^4$ cm and $3\times10^3$ cm in two experiments. Several individual resonances have been resolved below 60 ev as well as several packets of levels at higher energies. Yields of $As^{77}$, $Mo^{99}$, $Ag^{111}$, $Cd^{115}$, and $Ba^{140}$ were determined. Results to date show that there are no highly symmetric modes of

fission (i.e., $Ag^{111}$ or $Cd^{115}$ yields $\geq 1\%$) in the energy interval 9 ev to 500 ev with a fission cross section at resonance of more than 20 barns. Data concerning variations of 15–30% in the valley fission product yields will be presented.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[2] Participants: J. P. Balagna, J. W. Barnes, D. W. Barr, B. P. Bayhurst, A. L. Bond, E. A. Bryant, G. A. Cowan, B. J. Dropesky, W. B. Goad, G. W. Knobeloch, E. J. Lang, F. F. Moore, P. Q. Oliver, C. J. Orth, E. Panowski, R. J. Prestwood, E. E. Shaw, A. Turkevich, and F. J. Waddell.

**K6. Photoneutron Threshold Measurements.*** K. N. GELLER, E. G. MUIRHEAD, AND J. HALPERN, *University of Pennsylvania.*—Photoneutron thresholds of 45 mono- and di-isotopic elements have been measured using our 25-Mev betatron with improved energy stability. Neutron yields in the vicinity of threshold were measured in steps of approximately 25 kev. Thresholds were obtained by extrapolating the direct yield curve into the measured background. Other methods of extrapolation were used to refine this crude value. For most elements neutrons were detected directly by using three $BF_3$ counters embedded in a paraffin block.[1] For light elements, greatly improved sensitivity was obtained by measuring the annihilation radiation from the residual positron activity with two NaI(Tl) crystals. The primary energy calibration of the betatron is based on the thresholds of the $(\gamma,n)$ reaction in D(2.226 Mev), $Bi^{209}$(7.43 Mev), $Cu^{63}$(10.83 Mev), $P^{31}$(12.33 Mev), and of elastic scattering of the photon isochromat by the 15.11-Mev level in $C^{12}$. The final energy calibration includes many other photoneutron thresholds as secondary standards. The energy scale so obtained is linear on an electron momentum *versus* "dekavider" setting plot to within the accuracy of the measurements ($\pm 25$ kev in the range 2–20 Mev). Comparison of the present results with other threshold measurements and with recent mass data will be made.

* Supported in part by the Air Research Development Command and by the Office of Naval Research.
[1] Halpern, Mann, and Nathans, Rev. Sci. Instr. 23, 678 (1952).

**K7. Differential Cross Section for Elastic Scattering of 3.7-Mev Neutrons from Germanium and Selenium.*** D. W. KENT, SATYA PAL PURI, AND S. C. SNOWDON, *Bartol Research Foundation.*—The measurements to be presented, together with our recent measurements on S, Fe, Co, Ni, Cu, and Zn,[1] demonstrate the existence of a resonance structure in the nonelastic cross sections as a function of $A$, corresponding to the observed resonance structure of total elastic cross sections. The nonelastic cross sections obtained for germanium and selenium are $1.99 \pm 0.10$ and $2.37 \pm 0.18$ barns, respectively. Detailed pulse height analysis with a 100-channel analyzer has been used to provide a more selective discriminator against $\gamma$ rays and inelastically scattered neutrons.

* Assisted by the U. S. Atomic Energy Commission.
[1] Machwe, Kent, and Snowdon, Phys. Rev. (submitted for publication).

**K8. Survey of Inelastic Neutron Scattering from Even-$Z$ Elements.*** D. M. VAN PATTER, M. A. ROTHMAN, N. NATH, S. S. MALIK, AND C. E. MANDEVILLE, *Bartol Research Foundation.*—A survey of $\gamma$-ray spectra from inelastic neutron scattering of some fourteen even-$Z$ elements (Ti to Nd) is in progress, for several neutron energies from 1 to 2.7 Mev. The basic objective is to obtain information concerning energy and spin systematics[1] for even-even nuclei with $A = 46-150$. Using Hauser-Feshbach calculations,[2] it is estimated that for nuclei with $A \simeq 56$, the $(n,n')$ cross section for a second $2+$ level should exceed that expected for a $4+$ level by as much as a factor of five. For many of the nuclei studied, the relative intensities of the $\gamma$ rays observed from the first two levels can be related to the ratio of the $(n,n)'$ cross sections for these levels. In order to test if the statistical assumptions of the theory are approximately satisfied in this experiment, several nuclei have been studied for which the spin of the second level is known. In addition, results have been obtained for several nuclei for which the spin of the second level is unknown. This survey has already revealed many new $\gamma$ rays, some of which may be assigned to new levels in particular nuclei by the study of $\gamma$-$\gamma$ coincidences.

* Assisted by the U. S. Atomic Energy Commission.
[1] D. M. Van Patter, Bull. Am. Phys. Soc. Ser. II, 3, 212 (1958).
[2] W. S. Emmerich, Westinghouse Report 60-94511-6-R8 (1955).

**K9. Energy Levels of $F^{20}$ by Inelastic Neutron Scattering.*** M. A. ROTHMAN, N. NATH, AND D. M. VAN PATTER, *Bartol Research Foundation.*—Inelastic neutron scattering in yttrium metal has been studied by direct observation of the de-excitation gamma rays. Gamma rays from the known states at 0.913 and 1.53 Mev are seen, as well as a new level at 1.8 Mev. The excitation curve for the 0.913-Mev metastable state has been observed and has the same general features as that previously obtained.[1] However, a search for the level reported at 1.2 Mev produced a negative result. This is in agreement with results obtained by time-of-flight measurements at Brookhaven.[2]

* Assisted by the U. S. Atomic Energy Commission.
[1] C. P. Swann and F. R. Metzger, Phys. Rev. 100, 1329 (1955).
[2] Landon, Elwyn, Glasoe, and Oleksa, BNL 3780.

**K10. Slow Neutron Scattering from Methane and Steam.*** R. M. BRUGGER, R. E. SCHMUNK, L. W. MCCLELLAN, AND J. E. EVANS, *Phillips Petroleum Company.*—The MTR velocity selector, which consists of two-phased Fermi-type choppers, and a 100-channel time analyzer have been used to measure the energy distributions of slow neutrons scattered at 90° from samples of methane and steam. The methane sample was at 22°C, 102 psig, and had neutron transmissions from 0.84 to 0.92. The saturated steam sample was at 150°C, and had neutron transmissions from 0.96 to 0.98. Since vanadium has been shown to have very little inelastic scattering, a 0.094-in. thick sample of vanadium metal was used to determine the energy resolution of the incident neutrons. Data on these three samples will be reported for initial neutron energies of 0.48, 0.12, 0.08, 0.05, 0.04, 0.025, and 0.014 ev. For the methane and steam samples, at most of the above energies, more than half of the scattering is inelastic.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**K11. Measurement of Excitations in Water by Scattering of Cold Neutrons.** H. PALEVSKY, W. KLEY,* AND D. J. HUGHES, *Brookhaven National Laboratory.*—A beam of beryllium-filtered neutrons was scattered from thin films (about 0.2 mm) of $H_2O$ and the spectrum of the neutron scattered through 90° was analyzed with the Brookhaven slow chopper equipment. The scattered spectrum was found to be displaced towards higher energy by $0.26 \times 10^{-3}$ ev, and in addition, five peaks were observed that were not present in the incident beam. Three peaks represent cases in which the neutrons gain energy from the liquid and correspond to transitions with energies of 58, 23, and 6.5 ($\times 10^{-3}$ ev). These transitions have previously been found[1] by Raman measurements and interpreted as hindered rotations and vibrations. The other two peaks correspond to transfer of energy from neutrons to the liquid, with transition energies of approximately 1.48 and 0.77 ($\times 10^{-3}$ ev). The neutron measurements give the first experimental data on such low energy transitions in $H_2O$ in liquid form. Similar levels have been found in water vapor using microwaves. Although the microwave levels have been correlated with transitions[2] between different modes of the free rotation of the water molecule, it would seem unlikely that the same processes should occur in the liquid state.

* Guest Scientist from University of Freiburg.
[1] M. Magat, Ann. phys. 6, 108 (1936).
[2] King, Hainer, and Cross, Phys. Rev. 71, 433 (1947).

THURSDAY MORNING AT 10:00

Boston Room

(T. D. LEE presiding)

***Symposium on Cooperative Phenomena***

**KA1. Properties of Nuclear Matter.** V. F. WEISSKOPF, *M.I.T.* (40 min.)

**KA2. Perturbation Theory of Many-Particle Systems.** N. M. HUGENHOLTZ, *Institute for Advanced Study.* (40 min.)

**KA3. Recent Progress and New Problems in the Theory of Superconductivity.** DAVID PINES, *Institute for Advanced Study.* (40 min.)

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THURSDAY AFTERNOON AT 2:00

Manhattan Center

(G. E. UHLENBECK presiding)

***Joint Ceremonial Session of APS and AAPT***

***Retiring Presidential Address of the American Physical Society***

**L1. High-Speed Rotation.** J. W. BEAMS, *University of Virginia.*

(C. J. OVERBECK presiding)

***Presentation of the Oersted Medal of the AAPT***

***Response of the Oersted Medallist***

**L2. On Colleagues and Clients.** PAUL KIRKPATRICK, *Stanford University.*

***Seventeenth Richtmyer Memorial Lecture of the AAPT***

**L3. Masers and Their Applications.** C. H. TOWNES, *Columbia University.*

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FRIDAY MORNING AT 9:45

Panel Room

(D. J. HUGHES presiding)

***Neutron Spectroscopy, I***

**M1. Joint Brookhaven-Chalk River Fast Chopper Installation at NRU.** R. L. ZIMMERMAN, H. PALEVSKY, AND D. J. HUGHES, *Brookhaven National Laboratory,* AND C. H. WESCOTT, *Chalk River Laboratories.*—A fast chopper apparatus has been installed at the NRU reactor at Chalk River. The major pieces of equipment are a Brookhaven type fast chopper rotor and vacuum housing, a 1024-channel time-of-flight analyzer, and various types of detectors, including a bank of 384 $BF_3$ counters, and a NaI $\gamma$-ray spectrometer. The beam hole consists of an elliptical tube $3\frac{1}{2}$ in.$\times 4\frac{1}{2}$ in. passing through a central plane of the reactor between two columns of fuel elements. $D_2O$ contained in a thin-walled aluminum can, located in the beam tube at the center line of the reactor, serves as a scatterer. Measurements carried out at low power indicate that at full power the thermal flux at the radiating $D_2O$ surface will be $\sim 2\times 10^{14}$ n/cm$^2$/sec. The cadmium ratio measured with a $1/v$ detector is $\sim$40. The average energy of background neutrons was found to be approximately 3.5 Mev, consistent with the fact that the beam does not "see" any fuel elements. The spectra of $\gamma$ rays coming from the scatterer was measured with a 2-in. diameter$\times$2-in. thick NaI crystal. From these measurements it was concluded that the number of $\gamma$ rays with energy above 0.5 Mev is equal to the number of thermal neutrons. The foregoing fast chopper equipment at Chalk River will give open-beam counting rates of $\sim$200 counts/$\mu$sec channel/min in the energy region 10–1000 ev with an instrument resolution 0.05 $\mu$sec/m.

**M2. I. Slow Neutron Resonances in $U^{238}$.†** J. ROSEN, W. W. HAVENS, JR., J. RAINWATER, AND S. DESJARDINS, *Columbia University.*—The Nevis Synchrocyclotron Neutron Velocity Selector has been used to study the resonances in $U^{238}$. The data were taken using a 2000-channel analyzer with 0.1-$\mu$sec channel widths and a source detector distance of 35.22 m. Thus the resolution width is less than 0.01 $\mu$sec/m. Self-indication measurements were performed using samples with thickness $1/n = 82$ and 425 barns/atom. The effects measured at the detector are $C(1-T_1)$ and $CT_2(1-T_1)$ where $T_1$ and $T_2$

are the transmission of the detector and transmission samples, respectively, and $C$=(flux) (detector efficiency) ($\sigma_{capture}/\sigma_{total}$). The $\Gamma_n^0$'s for 48 resonances between 100 and 1000 ev have been determined. For 28 of these resonances $\Gamma_\gamma$ has also been obtained. The average properties are $\langle\Gamma_n^0\rangle_{Av}D=0.94\times10^{-24}$, $\bar{D}=18.5$ ev, and $\langle\Gamma_\gamma\rangle_{Av}=24$ mv. Partial widths and level spacing distributions and fluctuations will be discussed.

† This work was partially supported by the U. S. Atomic Energy Commission.

**M3. II. Slow Neutron Resonances in Ta, Ag, Cd.†** S. DESJARDINS, W. W. HAVENS, JR., J. RAINWATER, AND J. ROSEN, *Columbia University.*—The Nevis Neutron Velocity Selector, together with the self-detection methods described in the previous abstract, have been used to investigate the resonance levels in Ta, Ag, and Cd. For Ta 63 $\Gamma_n$'s and 11 $\Gamma_\gamma$'s have been determined for resonances in the energy interval from 70 to 330 ev. The analysis of levels in Ag has been performed for levels up to 450 ev and for Cd to 500 ev. Many small levels, which have not previously been reported, are observed in Ag, in the energy interval from 100 to 200 ev, only when high statistical accuracy is achieved. Most of these small levels are probably caused by $p$-wave interactions. For a few of the levels in Ag and Cd, the value of the spin can be inferred by comparing $g\Gamma_n$ with the value of $\Gamma_n$ determined by subtracting $\Gamma_\gamma$ from $\Gamma$.

† This work was partially supported by the U. S. Atomic Energy Commission.

**M4. Neutron Total Cross Sections of Vanadium, Cobalt, and Bismuth from 3 to 30 kev.** F. W. K. FIRK, M. C. MOXON, AND J. E. LYNN, *Atomic Energy Research Establishment, Harwell* (introduced by E. Bretscher).—A considerable improvement in the resolution of the Harwell 15-Mev linear accelerator and time-of-flight spectrometer has recently been achieved.* By reducing the duration of the neutron burst to 0.25 $\mu$sec and the timing channels to 0.17 $\mu$sec a nominal resolution of $<10$ m$\mu$sec m$^{-1}$ is obtained when using a flight path of 31.8 m. The improved performance of the spectrometer is demonstrated by measurements of the total cross sections of vanadium, cobalt, and bismuth in the energy region 3 to 30 kev. Resonances at the following energies are observed: vanadium—4.0, 6.9, 11.0 (15.0), (15.8), 20.9, and 28 kev; cobalt—4.32, (4.96), (5.16), 7.8, 10.4, (12.6), (15.1), (16.2), 21.0, and 23.4 kev; bismuth—(4.95), 12.0, 15.6, and 28 kev. The resonances in parentheses have not been previously resolved. Resonance parameters will be presented.

* Firk, Reid, and Gallagher, Nuclear Instr. (to be published).

**M5. Parameters of Low Energy Neutron Resonances in Mercury.** J. R. BIRD, M. C. MOXON, AND F. W. K. FIRK, *Atomic Energy Research Establishment, Harwell* (introduced by E. Bretscher).—The Harwell 15-Mev linear accelerator and associated time-of-flight equipment has been used to determine the spins of some of the slow neutron resonances in mercury using two independent methods. The first method involves a study of the shape of the $\gamma$-ray spectra from resonant neutron capture in the spin $\frac{1}{2}$, odd-even isotope $Hg^{199}$.† The second method is the conventional area analysis technique for transmission data from samples of various thickness. In favorable cases this method can indicate the spin of a resonance if the radiation width is assumed to be constant for a particular isotope. The two methods give consistent results and the combined data will be presented for a number of mercury resonances.

† H. H. Landon and E. R. Rae, Phys. Rev. 107, 1333 (1957).

**M6. Total Neutron Cross Section of Krypton.*** R. E. CHRIEN, *Brookhaven National Laboratory,* AND D. P. MANN AND W. W. WATSON, *Yale University.*—The transmission of krypton to neutrons of energies from 10 ev to 10 kev has been investigated with the BNL fast chopper and time-of-flight apparatus. Samples of normal krypton and krypton enriched in the light isotopes were prepared by a thermal diffusion apparatus previously described.[1] Neutron widths and isotopic identifications have been determined for the following levels: 27.9 ev in $Kr^{83}$, 39.8 ev in $Kr^{82}$, 106 ev in $Kr^{80}$, and 2200 ev in $Kr^{82}$. In addition total widths and radiation widths have been obtained for the 27.9- and the 106-ev levels by thick-thin area analysis. Resonances in krypton have also been observed at 232, 515, and 640 ev.

* Under the auspices of the U. S. Atomic Energy Commission.
[1] Mann, Watson, and Schwartz, Bull. Am. Phys. Soc. Ser. II, 3, 176 (1958).

**M7. Neutron Resonance Parameters of $Am^{241}$.** J. A. HARVEY, R. C. BLOCK, AND G. G. SLAUGHTER, *Oak Ridge National Laboratory.*—The total cross section of a thin $Am^{241}$ (470-yr half-life) sample was measured over the energy range 0.3 to 10.3 ev with the ORNL fast chopper time-of-flight spectrometer. A total of ten definite and three probable resonances were observed in this energy range. Uopn analyzing these resonances for parameters, a strength function ($\langle\Gamma_n^0\rangle_{Av}D$) of $(1.7\pm0.5)\times10^{-4}$ per spin state was obtained over the energy range 0.3 to 10.3 ev and an average level spacing of $(1.4\pm0.4)$ ev per spin state was obtained over the energy range 0.3 to $\sim$7 ev. These measurements are being repeated and extended to higher energies with thicker $Am^{240}$ samples; these results will also be presented.

**M8. Total Cross Section Measurements of $Pu^{240}$, $Np^{237}$, and Radioactive Fission Products near Thermal Energies.** R. C. BLOCK, G. G. SLAUGHTER, AND J. A. HARVEY, *Oak Ridge National Laboratory.*—The total cross section of 92.19% enriched $Pu^{240}$ (6600-yr half-life) was measured from 0.02 to $\sim$1 ev with the ORNL fast chopper time-of-flight spectrometer with an 11.53-m flight path. A preliminary value of $283\pm8$ barns for the 2200 m/sec absorption cross section was obtained after correcting the data for the contributions of the other plutonium isotopes and an assumed 10-barn scattering cross section. Measurements upon samples of $Np^{237}$ and $I^{129}$ have been completed and these data will be presented. Measurements of other radioactive fission product cross sections are in progress and will be reported upon.

**M9. Capture $\gamma$ Rays from Neutron Resonances.*** M. K. BRUSSEL AND J. D. FOX, *Brookhaven National Laboratory.*—The study of $\gamma$ radiation following resonance capture of slow neutrons is continuing. The original equipment[1] has been modified to permit greater stability and $\gamma$-ray energy resolution. This has been accomplished by reducing the six detector photomultiplier tube voltages and by transistorizing the circuit which mixes their outputs. The over-all pulse height stability of the equipment is now better than 1% per day. The energy resolution (full width at half-maximum) is approximately 5% for 7.5-Mev $\gamma$ rays. The memory of the 1024 channel neutron time-of-flight analyzer has been subdivided to allow a simultaneous recording of data in two or more pulse height channels. Improved beam collimation has reduced background effects to the level of cosmic-ray background. In survey work, by comparing relative transition probabilities, the 11.9-ev resonance in $Pt^{195}$ has been assigned a spin of $J=1$, whereas the levels at 19.6 ev and 68 ev appear to indicate a spin of $J=0$. Previous[2] assignments of $J=1$ to the 34-ev resonance in $Hg^{199}$ are confirmed.

* Under the auspices of the U. S. Atomic Energy Commission.
[1] Fox, Zimmerman, Hughes, Palevsky, Brussel, and Chrien; Phys. Rev. 110, 1472 (1958).
[2] H. H. Landon and E. R. Rae, Phys. Rev. 107, 1333 (1957); Kennett, Bollinger, and Carpenter, Bull. Am. Phys. Soc. Ser. II, 3, 177 (1958).

**M10. Neutron Cross Section of Manganese.*** L. M. BOLLINGER, R. E. COTÉ, T. J. KENNETT, AND G. E. THOMAS, *Argonne National Laboratory.*—The neutron cross section of $Mn^{55}$ has been studied from 1 to 35 000 ev by transmission measurements. In addition, the rate of $\gamma$-ray production from neutron capture was measured as a function of neutron energy. The resolution used in the transmission measurements (12 mμsec/m) is narrow enough that the resonance structure observed below 17 kev is almost completely resolved. The preceding and other relevant data are considered in attempting to fit the measured total cross-section curve over a wide energy range. This fitting gives spin assignments of 2, 3, 3, 2, and 3 for the levels at 0.337, 1.08, 2.36, 7.08, and 8.75 kev, respectively.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**M11. Multiplicity of Gamma Rays from Resonance Neutron Capture.*** T. E. SPRINGER†‡ AND J. E. DRAPER, *Yale University.*—The multiplicity of neutron capture gamma rays has been measured in 24 resonances selected by time-of-flight of 13 elements between $A=110$ to 198. The counting rate from the sample to be measured of gamma-rays above 30 kev, detected in a collimated 4-in.×5-in. NaI(Tl) scintillator was compared to that from a $B^{10}$ sample. The following list gives the compound nucleus, the neutron resonance energy in ev, and the multiplicity for each resonance measured: $Ag^{110}$, 5.2, *4.9±0.3*; $Cd^{114}$, 0.178, *4.1±0.25*; $In^{116}$, 1.46, *4.4±0.2*; $In^{116}$, 3.86, *5.4±0.6*; $In^{116}$, 9.0, *4.1±0.4*; $Sm^{150}$, 0.097, *6.15±0.25*; $Sm^{150}$, 0.86, *5.0±0.4*; $Sm^{152}$, 8.0, *4.0±0.5*; $Eu^{152}$, 0.46, *4.4±0.3*; $Eu^{152}$, 1.0, *3.4±0.5*; $Gd^{155,6}$, 0.03, *4.6±0.2*; $Gd^{156}$, 2.64, *3.9±0.4*; $Dy^{164}$, 1.7, *4.5±1.0*; $Dy^{165}$, thermal, *3.0±0.2*; $Ho^{167}$, 3.9, *2.9±0.3*; $Er^{168}$, 0.47, *4.7±0.3*; $Er^{168}$, 5.97, *4.1±1.3*; $Tm^{170}$, 3.9, *3.7±0.3*; $Lu^{177}$, 0.14, *4.35±0.25*; $Lu^{177\,m\,178}$, 1.54, *3.9±0.3*; $Lu^{177}$, 2.61, *4.35±0.3*; $Hf^{179}$, 1.1, *4.2±0.2*; $Hf^{178}$, 2.38, *4.3±0.2*; $Au^{198}$, 4.9, *3.8±0.3*. Variations in the multiplicities of different resonances in the same isotope and systematics observed in the multiplicities of the elements measured will be discussed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† Atomic Development Mutual Fund Predoctoral Fellow.
‡ Now at Los Alamos Scientific Laboratory.

**M12. Neutron Strength Functions for Deformed Nuclei.** D. J. HUGHES, R. L. ZIMMERMAN, AND R. E. CHRIEN, *Brookhaven National Laboratory.*—The program of measurement of neutron strength functions with the Brookhaven fast chopper has been continued, with special emphasis on highly deformed nuclei near $A=180$. The strength function, or $\Gamma_n^0/D$ ratio (with $\Gamma_n^0$ the mean neutron width and $D$ the level spacing), has been determined both from parameters of individual levels in the conventional manner and by the average cross-section technique[1] in the kev energy range. The interest in the highly deformed nuclei stems from the fact that their strength functions do not agree with optical model calculations for spherical nuclei. Recently, calculations have been made by Chase, Wilets, and Edmonds,[2] based on deformations of a diffuse complex potential well corresponding to measured quadrupole moments. The resulting strength function has two distinct peaks in the $A=140$–$200$ range, as contrasted to the single peak for spherical nuclei. The present results exhibit two peaks at $A=145$ and 185, in good agreement in position and magnitude with the theoretical curve.

[1] D. J. Hughes and V. E. Pilcher, Phys. Rev. **100**, 1249(A) (1955).
[2] Chase, Wilets, and Edmonds, Phys. Rev. **110**, 1080 (1958).

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## FRIDAY MORNING AT 9:45

Grand Ballroom

(H. L. ANDERSON presiding)

### *Invited Papers on Pi and Mu Decay*

**MA1. Pi-Electron Decay.** A. V. TOLLESTRUP, *California Institute of Technology.* (30 min.)

**MA2. Rate of Pi-Electron Decay (Work at Berkeley).** K. M. CROWE, *University of California, Berkeley.* (30 min.)

**MA3. Momentum Spectrum and Asymmetry in the Decay of the Mu-Plus Meson.** R. J. PLANO, *Columbia University.* (30 min.)

**MA4. Theory of Mu Decay.** HENRY PRIMAKOFF, *Washington University.* (30 min.)

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## FRIDAY MORNING AT 10:00

Boston Room

(L. APKER presiding)

### *General Solid-State Physics*

**N1. Crystal Polymorphs of Ge, Si, and Some III-V Compounds.** D. P. MILLER AND M. E. JONES, *Texas Instruments, Inc.* (introduced by R. L. Petritz).—X-ray diffractometer measurements on oriented single crystals of Ge, Si, InSb, AlSb, and GaAs at temperatures from room temperature to 800°C indicate the coexistance of several rhombohedral and hexagonal phases. These are all related to the face centered cubic lattice, resulting from the appearance of hexagonal close packed "stacking faults" in the lattice 111 planes. One of the rhombohedral phases arises out of the distortion of the basic f.c.c. lattice under compression along the 111 direction by adjacent higher periodicity h.c.p. regions. These changes appear to occur equally in crystallographically equivalent directions in the structure as indicated by the appearance of both lines of rhombohedral "doublets" on the diffractometer trace of a particular crystal orientation setting.

**N2. Eigenspectra of Some Model Cubic Lattices.** G. ALLEN, *NASA Lewis Research Center.*—Allowed combinations of energy, $E$, and well-depth, $V_0$, have been computed for the Schroedinger equation of an electron in various cubic lattices. The potential and the eigenfunctions were both assumed to be spherically symmetric about each lattice point. Computations of the allowed $(E,V_0)$ pairs have been made using the nearest neighbor approximation for the whole range of the fraction of the lattice volume for which the potential is nonvanishing. For the region $E>0$, graphs of these computations exhibit crossings of boundaries between regions of allowed and regions of unallowed $(E,V_0)$ combinations which is similar to the case of one-dimensional lattices with rectangular-well potentials.

**N3. Calculation of Elastic Constants on the Valence Force Model.** ROBERT W. KEYES, *Westinghouse Research Laboratory.*—The elastic constants of the diamond lattice crystals, C, Si, and Ge, have been calculated on the valence force model, which assumes nearest neighbor bond stretching and angle bending forces. The values for the force constants for tetrahedral bonding were obtained from the spectra of the molecules of the types $XH_4$ and $X_2H_6$. The results are, in cgs units,

| Element | $k_r$ | $k_\beta$ | $\frac{1}{3}(C_{11}+2C_{12})$ | $\frac{1}{3}(C_{11}-C_{12})$ |
|---|---|---|---|---|
| C | $5.17\times10^5$ | $0.55\times10^{-11}$ | $4.8\times10^{12}$ | $1.94\times10^{12}$ |
| Si | $1.92\times10^5$ | $0.41\times10^{-11}$ | $1.18\times10^{12}$ | $0.41\times10^{12}$ |
| Ge | $1.21\times10^5$ | $0.29\times10^{-11}$ | $0.71\times10^{12}$ | $0.26\times10^{12}$ |

The compressibilities are predicted to better than 20%; the shear constants are considerably less accurate than this. This is not surprising, since the values of $k_\beta$ actually differ from one molecule to another. In all cases the agreement with the properties of the solid is much better than that found by Lyons,[1] who used a similar model to calculate Young's modulus of some polymers. This tends to confirm Lyons' idea that the discrepancy in the latter case is due to a lack of crystallinity in the polymers.

[1] W. James Lyons, J. Appl. Phys. **29**, 1429 (1958).

**N4. Multiphonon Acoustic Lattice Mobility.** H. D. VASILEFF, *Sylvania Electric Products, Inc.*—On the basis of the rigid ion model the exact perturbation is expressed in terms of Fourier integrals. The transition probabilities are determined by averaging over all initial vibrational states and summing over all final. The scattering is given by the matrix elements of multiple gradients of the thermally averaged crystal potential

$$\langle V(r)\rangle = \exp(\alpha\nabla^2)\,V(r),$$

where $\alpha$ is a temperature dependent factor related to the Debye function $\Phi(\Theta/T)$. Emission and absorption probabilities for two and three phonons will be given. The final mobility expression involves, in addition to the $T^{-1}$ factor, an exponential factor $\exp(b\alpha C)$, and a temperature dependent Goodwin-Statton integral. Thus, the exponent of the temperature depends on the magnitude of the interaction constant $C$. Results will be discussed.

**N5. A Reformulation of the Electron-Phonon Interaction in Nonpolar Crystals.** G. D. WHITFIELD, *IBM Watson Laboratory and Columbia University.*—A new set of electron wave functions, called the orthogonalized deformed Bloch (O.D.B.) functions, are introduced. These are essentially Bloch functions of the variable $\mathbf{y}=\mathbf{x}-\mathbf{u}$, where $\mathbf{x}$ is the position of the electron and $\mathbf{u}$ is a smooth function defined so that, when $\mathbf{x}$ is equal to the instantaneous position of one of the ion cores, $\mathbf{u}$ is the displacement of that ion core from its mean position. These functions are like the adiabatic (Born-Oppenheimer) functions in that they deform with the lattice; but they acquire all the mathematical properties of the Bloch functions when written as functions of $\mathbf{y}$. The Hamiltonian in the O.B.D. representation can be approximated by assuming that the strains are small (whereas in the Bloch representation one assumes that the displacements are small). The results of these two treatments are compared using the deformable and rigid ion models, and it is proved that they both give the same first order transition rate. A deformation potential theorem is proven for the matrix elements of the O.B.D. (rather than the Bloch) functions. The proof is straightforward, and the theorem amenable to generalization.

**N6. Some Observations of Plastic Behavior of Ionic Crystals.** ROBERT G. GREENLER AND WILLIAM S. ROTHWELL, *Research Laboratories, Allis-Chalmers Manufacturing Company.*—NaCl crystals which have been made ductile by immersion in water may conveniently be dried and tested in air. The plastic properties resulting from this treatment are observed to be retained for at least several months when the crystals are stored in air at room temperature. Untreated crystals have been strained as much as 10% when tested several days after being cleaved in air. The effect of treating LiF samples with anhydrous HF and MgO crystals with hot $H_2SO_4$ also has been investigated. Stress-strain curves describing the effects of these treatments will be shown and their significance discussed.

**N7. Anomalous Photovoltaic Effect in ZnS Single Crystals.** A. LEMPICKI, *Sylvania Electric Products Inc.*—Larger-than-band-gap photovoltages have been observed in both cubic and hexagonal crystals of ZnS with stacking faults. Under monochromatic excitation the photovoltage measured parallel to the $c$ axis shows two sign reversals at about 3300 A and 3500 A and peaks at approximately 3250 A and 3400 A. The position of the 3400 A peak shifts by ~70 A depending on the crystal structure. In the direction perpendicular to the $c$ axis the photovoltage does not change sign and remains smaller than the band gap. Hexagonal crystals free of stacking faults do not show anomalous photovoltages. Heat treatment causes appearance of both. A pyroelectric polarization is found to be correlated with the sign of photovoltage.

**N8. Optical Properties of LiF and Isotopically Enriched LiF in the Infrared.** MILTON GOTTLIEB, *General Atomic, and University of Pennsylvania,* AND J. R. NELSON, *Convair.*—Measurements of the reflectivity at normal incidence of LiF in the infrared have been made from 2 microns to 60 microns using prism and grating spectrometers. Measurements were done at room temperature and at liquid nitrogen temperature. By a previously described analysis* (performed on the IBM 704 computer) involving the Fresnel reflection equation and a Kramers-Kronig dispersion relation, the index of refraction, absorption coefficient, and real and complex dielectric constants were obtained. Reflectivity measurements were done on $Li^6F$ and $Li^7F$ by evaporating relatively thick films of the material on to substrates of single crystal natural LiF. The lattice constants of $Li^6F$ and $Li^7F$ are 4.027 A and 4.026 A, respectively, so there is good matching of substrate and film lattices. The reflection spectrum shows secondary structure on the short wavelength side of the reststrahl peak, and it was found that the main peak shifted as the square root of the reduced mass, while the position of the secondary maximum was not as strongly dependent on the mass. Temperature and mass dependence of the corresponding structure in the optical constants was also obtained.

* Nelson, Schainblatt, and Hartman, Bull. Am. Phys. Soc. Ser. II, 3, 272 (1958).

**N9. Absorption Spectrum of KCl:Tl at Low Temperatures.** DAVID A. PATTERSON, *U. S. Naval Research Laboratory.*—The ultraviolet absorption spectrum of single crystal KCl:Tl

has been accurately measured down to 187 mμ at 295°, 77°, and 4°K. Both major bands ("*C*" band at 196 mμ, "*A*" band at 247 mμ) show pronounced asymmetry at room temperature which disappears at low temperature. The half-width of the "*A*" band at room temperature computed from low-temperature emission and absorption data is found to be 20% less than the experimental value. These results, plus previously reported excitation data, indicate that both the "*A*" and "*C*" bands are complex rather than single. As a partial explanation, it is suggested that two slightly different singlet thallium ions are active, one in a local CsCl-type lattice and another in NaCl-type surroundings. Absorption and excitation data interpreted in this light would indicate that the CsCl-type center is preferred at low temperatures and low thallium concentrations.

**N10. Thermal Conductivity of MnO, CoO, and NiO Crystals.*** GLEN A. SLACK, *General Electric Research Laboratory.*—The thermal conductivity of a number of different single crystals of MnO, CoO, and NiO has been measured from 3°K to 300°K. The energy transport appears to be via phonons in all cases. The thermal conductivities at 300°K are 0.10, 0.12, 0.41 w/cm deg for MnO, CoO, and NiO, respectively. All three exhibit a paramagnetic-antiferromagnetic transition, and the first two show a minimum in the thermal conductivity *versus* temperature curve near their Néel points of 120°K and 290°K. The minimum at the Néel point is probably caused by a phonon-spin interaction. Thus such a minimum may occur in NiO at its Néel point of 525°K. The thermal conductivity of NiO containing added impurities has also been studied. The effect of 0.1 atom percent lithium is small, whereas 5 atom percent Co reduces the thermal conductivity at 300°K by about a factor of two. Some explanation of the magnitude and temperature dependence of the results at temperatures above 30°K can be given if the phonon-spin interaction is considered. The thermal conductivity at temperatures less than 30°K is lower than the boundary scattering limit by a factor of 100 or more.

* Supported in part by the U. S. Air Force (WADC).

**N11. Thermal Conductivity of Solid Argon.** D. J. LAWRENCE, E. W. GUPTILL, AND A. T. STEWART, *Dalhousie University.*—The thermal conductivity of solid argon has been determined by a new method. Gaseous argon flows at a constant rate into a long glass cylinder which is immersed in liquid air. Solid argon forms a clear polycrystalline layer of uniform thickness on the inside of the tube. The heat of sublimation flows through the solid argon, the thickness of which is determined from the integrated gas flow. The temperature of the inside surface of the solid argon is determined by the vapor pressure of the flowing argon gas and the bath temperature by the vapor pressure when the flow of gas is stopped. The thermal conductivity of the solid argon can be obtained from the change of temperature gradient as the thickness of the layer increases. The thickness of the glass cylinder and its conductivity do not enter the calculations. The glass tube was 2.5 cm in diameter and was immersed about 26 cm in liquid air. Using 193 joules/g for the heat of sublimation, the data yield $2.65 \pm 0.2$ mw/cm°C for the thermal conductivity at 80°K. This figure is slightly lower than, but compatible with, the results of White and Woods[1] and gives a value of $B$ in $k = B/T$ of about 210 mw/cm.

[1] G. K. White and S. B. Woods, Phil. Mag. **3**, 785 (1958).

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## FRIDAY MORNING AT 10:00

Governor Clinton Hotel

(R. V. POUND presiding)

### *Invited Papers*

**NA1. Hyperfine Structure of Some Antimony and Bismuth Isotopes.** KENNETH SMITH, *University of California, Berkeley.* (30 min.)

**NA2. Dynamic Methods of Orienting Nuclei.** FRANK PIPKIN, *Harvard University.* (30 min.)

**NA3. Free-Electron Cyclotron Resonance and the Magnetic Moments of the Electron and Proton.** W. A. HARDY, *Harvard University.* (30 min.)

**NA4. Modification of Magnetic Resonance Line Shape in Double-Resonance Experiments.** J. H. BURGESS, *Stanford University.* (30 min.)

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## FRIDAY MORNING AT 9:45

Empire Room

(A. PAIS presiding)

### *Theoretical Physics IV, Including Strange-Particle Theory*

**P1. Σ-Mixing Effects in the Hypertriton.*** M. T. VAUGHN, *Purdue University.*—A variational calculation has been made to estimate the contribution of the off-diagonal (Σ mixing) terms of the Λ-nucleon potential to the binding of the hypertriton. Two terms were used in the semiphenomenological potential tried here; the first was a Σ-mixing term of Yukawa shape and range one pion Compton wavelength corresponding to the second-order potential calculated by Lichtenberg and Ross[1]; the second term was a Yukawa potential containing both diagonal and off-diagonal terms of range ~one-half pion Compton wavelength (0.6 f and 0.8 f were used), corresponding roughly to the fourth-order potential of Lichtenberg and Ross. Tensor forces were replaced by "equivalent" central potentials throughout. For various strengths of the second-order term, the strength of the fourth-order term necessary to produce the observed hypertrition binding energy was determined by

a variational calculation. It was found that the Σ-mixing terms contribute 20–40% of the effective Λ-deuteron potential for reasonable choices of the strength of the second-order potential.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] D. B. Lichtenberg and M. Ross, Phys. Rev. 107, 1714 (1957).

**P2. Effect of a Hard Core in the Λ-Nucleon Potential.*** T. N. TRUONG, *Cornell University* (introduced by B. W. Downs).—Studies of the hypernuclear three-body system (the hypertrition ${}_{\Lambda}H^3$) have shown that, in absence of hard cores, the Λ-nucleon potential is not strong enough to bind the two-body hypernuclear system.[1] It is to be expected that, if the Λ-nucleon potential has a hard core with radius exceeding some critical value, the existence of the hypertriton would imply the existence of the hyperdeuteron.[2] In this work the strength of the Λ-nucleon potential required to account for the observed binding of the hypertriton is calculated by a variational method. Both Λ-nucleon and nucleon-nucleon potentials are assumed to have hard cores of the same radius; the range of the former potential is assumed to be shorter than that of the latter. Calculations were made for hard core radii of 0.4 and 0.6 fermi. The results indicate that the hyperdeuteron might exist if the hard core radius exceeds 0.5 fermi. This is also in agreement with a previous estimate of Lichtenberg.[3]

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] See, for example, R. H. Dalitz and B. W. Downs, Phys. Rev. 111, 967 (1958).
[2] For a similar comparison of the two- and three-body nucleon systems, see Kikuta, Morita, and Yamada, Progr. Theoret. Phys. 15, 222 (1956).
[3] D. B. Lichtenberg, Nuovo cimento 8, 463 (1958), adapted the results of reference 2 to the hypertrition and found that, for a hard core radius of 0.4 fermi, the hyperdeuteron is on the borderline of being bound.

**P3. $\Sigma^+p$ Interaction.*** H. Y. CHIU, *Cornell University*.—The existence of a bound $\Sigma^+p$ system is indicated by a recent experiment.[1] The existence of such a system is a consequence of the global symmetry coupling scheme suggested by Gell-Mann *et al.* The exchange potential between $\Sigma^+$ and $\Lambda^0$ has been calculated assuming pion exchange force and the $\frac{3}{2}$–$\frac{3}{2}$ state resonance. This potential is applied to the calculation of the transition probability for $\Sigma^+$ to convert to $\Lambda^0$ inside the nucleus. The probability that $\Sigma^+p$ will emerge as a bound system is then calculated by using the conventional "boiling off" theory.

* Supported in part by the joint program of the Office of the Naval Research and the U. S. Atomic Energy Commission.
[1] Baldo-Ceolin, Fry, Greening, Huzita, and Limentani, Nuovo cimento 6, 144 (1957).

**P4. Photoproduction of *K* Mesons and *K*-Hyperon Parities.*** RICHARD H. CAPPS, *Cornell University*.—An investigation is made of the possibility of determining the intrinsic parities relative to the nucleon of $K$-Λ and $K$-Σ pairs by measuring the cross sections for photoproduction of these pairs from nucleons near threshold. The low-energy $S$ and $P$ wave contributions are calculated in a perturbation theory similar to that of Kawaguchi and Moravcsik.[1] The question concerning the combination of nucleon and hyperon magnetic moments that is effective in the process is clarified. The calculated cross sections are quite different from those given in the long photon wavelength approximation by Feld and Costa.[2] For most reasonable choices of the hyperon anomalous magnetic moments, certain calculated ratios of the close-to-threshold cross sections corresponding to different $K$-Λ and $K$-Σ charge states are quite sensitive to the $K$-hyperon parity. A model, in which the anomalous moments are the result of globally symmetric pion interactions, is used to illustrate the conclusions.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] M. Kawaguchi and M. J. Moravcsik, Phys. Rev. 107, 563 (1957).
[2] B. T. Feld and G. Costa, Phys. Rev. 110, 968 (1958).

**P5. Nuclear Capture of *K* Mesons by Deuterons.*** ROBERT KARPLUS AND LEONARD RODBERG, *University of California, Berkeley*.—Evidence has accumulated that the reaction[1] $K^-+D\rightarrow P+\pi^-+\Lambda$ can occur as a two-step process (1) $K^-+(P+N)\rightarrow\pi^-+(\Sigma^++N)$ or $\pi^-+(\Sigma^0+P)\rightarrow\pi^-+\Lambda^0+P$. This competes with the reaction (2) $K^-+D\rightarrow\pi^-+\Sigma^++N$ or $\pi^-+\Sigma^0+P$ in which the nucleon and Σ are in a state with isotopic spin $T=\frac{1}{2}$. Under the assumption that the two steps in reaction (1) occur independently through short range interactions (impluse approximation), we have related the branching ratio $R=(1)/(2)$ to the Σ-nucleon scattering matrix. The large measured value of $R\sim\frac{2}{3}$ can be accounted for if the reactions proceed primarily through one of the partial waves shown in Table I. The magnitude of the nuclear capture rates

TABLE I.

| | Orbit of $K$ meson | $K^-+n\rightarrow\Sigma+\pi$ | $\Sigma+n\rightarrow\Lambda+n$ |
|---|---|---|---|
| (a) | $s$ | $s$-wave incident | $s$-wave incident |
| (b) | $p$ | $p$-wave incident | $s$-wave incident |
| (c) | $p$ | $s$-wave incident | $s$, $p$, and $d$-wave incident |

compared to atomic radiation or collision rates suggests that the capture takes place from a $p$ orbit. The relative parities of the strange particles do not affect this conclusion but do affect the energy spectra and angular distributions.

* Supported in part by the Air Force Office of Scientific Research and by a grant from the National Science Foundation.
[1] Horwitz, Miller, Murray, Schwartz, and Taft, UCRL-8462 [Bull. Am. Phys. Soc. Ser. II, 3, 377 (1958)].

**P6. Symmetries of Strong Interactions.*** J. J. SAKURAI,† *Institute for Advanced Study*.—An attempt is made to deduce "useful" relations among strange particle reactions slightly stronger than those relations implied by charge independence in the conventional sense. As Pais has shown, there are no such relations that hold to all orders aside from those already contradicted by experiments. However, for the relative AΣ parity even and

$$G_{K\Lambda N}=\overset{+}{(-)}G_{K\Sigma N},G_{K\Lambda\Sigma}=\overset{+}{(-)}G_{K\Sigma\Sigma},$$

there exist relations that are valid as long as virtual pions play no roles (as is evident from a recent unpublished work of Feynman). In particular, if we have, in addition,

$$G_{\pi\Lambda\Sigma}=\overset{-}{(+)}G_{\pi\Sigma\Sigma}$$

(which means that the $\pi$ couplings and the $K$ couplings exhibit opposite four-dimensional symmetries), the *weaker* condition that pions emitted by $N$ and Ξ (Λ and Σ) be not absorbed by Λ and Σ ($N$ and Ξ) is sufficient for the validity of such relations. Empirical examples are given. With the foregoing assumptions the origins of the mass differences among the various baryons are discussed in relation to the "global symmetry" (high $\pi$ symmetry) model and also to the "cosmic symmetry" (high $K$ symmetry) model.

* Supported by a grant from the National Science Foundation.
† On leave of absence from the University of Chicago.

**P7. Decay of Hyperons and Mesons from Universal Fermi Interaction.*** A. FUJII AND M. KAWAGUCHI, *Purdue University*.—The decay of the hyperon, charged pion, and charged kaon except $K_{\pi 3}{}^+$ is investigated on the basis of the universal $V$-$A$ Fermi interaction with the idea of Gell-Mann tetrahedron, by treating the virtual baryon-antibaryon pair contribution in a phenomenological way. It is shown that the decay rate of $K_{\pi 2}{}^+$ calculated in terms of phenomenalogical parameters adjusted to the decay of $\pi^+$, $K_{e3}{}^+$, and $K_{\mu 3}{}^+$ is in agreement with experiment, thus suggesting the possible consistent picture of the model.

* Assisted by U. S. Air Force Office of Scientific Research.

**P8. $K_{\mu 2}$ Decay and Leptonic Decay of Hyperons.*** B. SAKITA, *University of Rochester* (introduced by C. Goebel).—The partial lifetime of $K \to \mu + \nu$ can be estimated by dispersion theory techniques as Goldberger and Treiman[1] have done for $\pi \to \mu + \nu$, if we assume that the antihyperon-nucleon scattering in $^1S_0$ is mainly absorptive. We take the primary Fermi interaction to be $(\bar{\Lambda}p)(\bar{\nu}\mu)$, of $V$-$A$ type. If for simplicity we neglect any $\Sigma^-$ coupling to the leptons, we find that the observed $K \to \mu + \nu$ rate implies $(g_{K\Lambda}{}^2 + 3g_{K\Sigma}{}^2/g_{\pi}g_{K\Lambda})(f_N{}^A/f_\Lambda{}^A) \sim 6$, where $f^A$ is the effective baryon axial vector $\beta$ coupling. Taking the current guess $(g_\pi/g_K)^2 \sim 10$, this would imply that the $\beta$ decay of the $\Lambda$ through axial vector should be slower than expected, similar to the conclusion of Oneda[2] for the vector part. Conversely, if the $\Lambda\beta$ decays normally, we would conclude $g_K \gtrsim g_\pi$. The $\beta$ decay of $\Sigma$ will also be discussed.

* Supported in part by the U. S. Atomic Energy Commission.
[1] M. Goldberger and S. Treiman, Phys. Rev. 110, 1178 (1958).
[2] S. Oneda (to be published).

**P9. Radiative Decays of the Pion.*** LAWRENCE E. EVANS, *The Johns Hopkins University*.—The discovery of the decay $\pi \to e + \nu$ with approximately the predicted abundance still leaves unsettled the question of the general nature of the interaction responsible for pion decay. Both a direct pion-lepton coupling and an intermediate coupling via the $V$-$A$ four-fermion interaction give a branching ratio of $12.7 \times 10^{-5}$ for electron decay relative to muon decay. The decay $\pi \to \mu + \nu + \gamma$, about $10^{-4}$ as probable as the nonradiative process, was investigated in an attempt to find effects which distinguish between these two coupling schemes. Matrix elements were obtained by invariance arguments similar to those of Treiman and Wyld.[1] Energy spectra, angular correlations,[2] and polarization effects will be discussed.

* Supported in part by Office of Scientific Research and National Science Foundation.
[1] S. B. Treiman and H. W. Wyld, Phys. Rev. 101, 1552 (1956).
[2] See also S. Kamefuchi and S. Oneda, Nuclear Phys. 6, 114 (1958).

**P10. Muon Capture in Certain Light Nuclei.** H. PRIMAKOFF, *Washington University*, AND A. FUJII, *Purdue University*.*—The partial transition rate of the muon-capture reactions $He^3 \to H^3$, $Li^6 \to He^6$, and $C^{12} \to B^{12}$ in which the daughter nucleus is found in its ground state is calculated by making use of the comparison with the beta-decay transition rate of the daughter nucleus from the ground state back to the ground state of the parent nucleus. Also the universality in coupling constants and coupling schemes, $V$-$A$, between beta decay and muon capture is assumed. The "induced" pseudoscalar interaction and the correction due to "divergenceless" current are both included in the basic Hamiltonian. The nuclear matrix element is evaluated using a variational trial wave function for $He^3$ and an oscillator potential wave function in $LS$ and $jj$ coupling shell theory for $Li^6$ and $C^{12}$, respectively. The calculated partial capture rate is in agreement with experiment which exists only for $C^{12}$ at present.

* Assisted by U. S. Air Force Office of Scientific Research.

**P11. Contribution of a Conserved Vector Current to the $\beta$-$\gamma$ Angular Correlation from Inner Bermsstrahlung in $\beta$ Decay.*** D. FIVEL AND T. FULTON, *The Jphns Hopkins University*.—We have calculated the $\beta$-$\gamma$ angular correlation from inner bremsstrahlung in the $\beta$ decay of $B^{12}$ and $N^{12}$, assuming a $V$-$A$ interaction with a conserved vector current.[1] The expected two correction terms are found. They are functions of the $\beta$ and $\gamma$ energies and of the relative angle. The $B^{12}$ and $N^{12}$ angular correlations differ only in the relative sign of the correction term proportional to the "weak magnetic moment" of the transition. The ratio of these angular correlations therefore differs from unity by a term proportional to the "weak magnetic moment." Due to the contribution of the meson cloud, this moment is $\sqrt{2}$ times the magnetic moment of the corresponding $\gamma$ transition in $C^{12}$ if charge independence is assumed.[1] For photons above 5 Mev the ratio differs from unity by more than 0.07. Detailed results of the calculations will be presented. Coulomb, relativistic, and nuclear bremsstrahlung corrections will also be discussed.

* Supported in part by the Office of Scientific Research and National Science Foundation.
[1] M. Gell-Mann, Phys. Rev. 111, 362 (1958).

**P12. On Chiral Spin $\frac{1}{2}$ Particles of Finite Mass.** E. J. SCHREMP, *U. S. Naval Research Laboratory*.—Through its dependence upon the definition chosen for the term "chirality," the formulation of a 4-component theory of chiral spin $\frac{1}{2}$ particles of finite mass admits a certain latitude of choice. Thus, one recently suggested definition presupposes an *8-dimensional* framework, whereas an alternative definition is possible for which only a *4-dimensional* framework is required. Using the group-space of the proper Lorentz group as our underlying framework of description, we have previously advanced a theory of chiral spin $\frac{1}{2}$ particles of the latter kind.[1] Initially, this theory lacked empirical support, as it conflicted with the principle of parity conservation, against which, at that time, no decisive test had yet been proposed. After parity nonconservation had been experimentally confirmed, however, our theory seemed to warrant publication in abbreviated form.[2] Here we show how, in this theory, the term "chirality" may be associated with a state of *nonorthogonality*, in the 4-dimensional sense, between the momentum vector and the spin density pseudovector of a spin $\frac{1}{2}$ particle, whether of finite or zero mass.

[1] E. J. Schremp, NRL Quart. Nucl. Sci. and Tech., July 1956 (unpublished), pp. 17–20, and January 1957 (unpublished), pp. 9–17.
[2] E. J. Schremp, Bull. Am. Phys. Soc. Ser. II, 2, 191 (1957); Phys. Rev. 108, 1076 (1957).

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## FRIDAY MORNING AT 9:45

## Terrace Room

## (KEITH BOYER presiding)

## *Fluid Dynamics II; Plasma Physics*

**PA1. Some Aspects of the Initiation of Detonation in Nitroglycerin.*** C. W. MAUTZ, *Los Alamos Scientific Laboratory*.—Streak camera, framing camera, and Kerr Cell photographs will be shown illustrating certain effects accompanying the development of detonation in underinitiated nitroglycerin.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

**PA2. Lycopodium Dust Particles in the Shock Tube Boundary Layer.*** RAYMOND J. EMRICH AND CHE-JEN CHEN, *Lehigh University*.—With the aim both to study the structure of the shock tube boundary layer and to study the mechanism of elevation of dust particles by shock induced flows, spark photographs have been taken in a glass-walled shock tube. Elevation of 30-$\mu$ diameter lycopodium particles, sprinkled on

the shock tube floor before the shock tube is operated, is observed in the laminar boundary layer. At one distance behind the shock in the turbulent boundary layer, most of the particles are found at about ⅔ of the way from the wall to the boundary layer edge, none are in the ⅓ of the layer closest to the wall, and a few are scattered in the outer part. A thick layer of dust disturbs the flow, leading to a thicker boundary layer and curvature of the shock front. From piles of dust, particles are blown upward at a small angle. Observation through a microscope with dark field illumination allows streaks to be photographed with a spark of a few microseconds duration. These streaks reveal both the magnitude and direction of the particle velocity.

* Supported by Office of Naval Research.

**PA3. Plasma Formation and Runaway Electrons.** G. W. STUART, *John Jay Hopkins Laboratory for Pure and Applied Science and General Dynamics Corporation.**—Theoretical descriptions hitherto devised to describe the transmutation, through ionization, of an originally cold gas into a plasma assume a Maxwell spectrum of electron velocity. Since electron cross sections decrease with increasing energy, the rate of collisional energy loss will fall below the gain from the electric field at some critical energy $E_c$. The electron then runs away into a region of still smaller cross section. The Maxwell spectrum assumption is thus suspect for those energetic electrons capable of ionizing. A model is calculated which takes account of runaway effects. The $E_c$ is determined from the energy-dependent drag on an electron resulting from both charged and neutral matter. The relatively small drag of neutrals requires careful treatment of initial conditions. The runaway rate follows that solution of the Fokker-Planck equation which expresses filling of the Maxwell tail. Assumption of unimpeded streaming above $E_c$ relates the runaway current to the electric field. Solution of Maxwell's equations yields the inductive effect of both runaway and slow electrons. Effects of ohmic heating and energy transfer between electrons and deuterons are included.

* Research on controlled thermonuclear reactions is a joint program carried on by General Atomic and the Texas Atomic Energy Research Foundation.

**PA4. Collapse of an Axially Symmetrical Pinch.** S. GARTENHAUS* AND L. M. TANNENWALD, *Lockheed MSD Research Laboratory.*—The exact solution and the derivation[1] of the equation of motion of an axially symmetric, but otherwise unrestricted, pinch surface corresponding to the Rosenbluth independent particle model has been obtained. For several situations of interest, solutions are found in parametric form. In the limit where the pinch may be considered as driven by an external circuit, it is shown that all parameters which describe the driving circuit may be absorbed into the definition of a new time scale. Numerical results which compare the collapse of a pinch surface with radial variations along its axis to one without such variations will be presented.

* Permanent address: Purdue University.
[1] H. W. Wyld, J. App. Phys. **29**, 1460 (1958).

**PA5. Measurement of a Plasma Density with 27-Mev Nitrogen Ions.** A. ZUCKER, M. L. HALBERT, AND C. E. HUNTING, *Oak Ridge National Laboratory.**—The problem of measurement of plasma densities of the order of $10^{14}$ atoms/cm$^3$ arises in connection with the work on controlled thermonuclear reactions performed at this laboratory. In this experiment the density of a low-pressure carbon arc drawing ~250 amp at 70 v was measured by bombarding the arc with 27-Mev nitrogen ions and observing the C-N elastic scattering events. Both the carbon and nitrogen atoms were counted with 0.005-in. CsI(Tl) crystals mounted on photomultiplier tubes. Coincidences between the two counters and pulse-height analysis on the nitrogen counter were used to discriminate against background pulses. It is estimated on the basis of meager experimental data that the most probable mean density of the arc is $10^{14}$ atoms/cm$^3$. The density of the arc is probably not larger than twice this value; however, the possibility exists that the coincidences observed were spurious, in which case our result is to be interpreted as an upper limit only.

* Operated for U. S. Atomic Energy Commission by Union Carbide Corporation.

**PA6. Containment and Heating of a Rotating Plasma.*** H. P. FURTH, *University of California, Livermore,*† AND O. A. ANDERSON, W. R. BAKER, A. BRATENAHL, W. B. KUNKEL, AND J. M. STONE, *University of California, Berkeley.*—By drawing a transient radial current across an axial magnetic field, a distribution of plasma can be made to rotate. Experiments begun in 1956 have measured rotary velocities in the $5\times10^6$ cm/sec range by means of Doppler shift analysis and have demonstrated essentially complete participation of the starting gas in the rotation by measuring the short-circuit current surges out of the rotor.[1] When an axial magnetic field of the mirror type is employed, centrifugal force inhibits the usual plasma leakage out of the mirrors. The usefulness of this effect in controlled thermonuclear work is evaluated. Plasma heating by viscous damping of the rotary motion is present and can be enhanced by manipulating the rotational emf.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† University of California, Livermore.
[1] Anderson, Baker, Bratenahl, Furth, and Kunkel, *Second International Conference on the Peaceful Uses of Atomic Energy, No. 330.* See also J. Appl. Phys. (to be published).

**PA7. Production of Ring Currents in a Shock Tube.*** F. R. SCOTT, H. G. VOORHIES, AND R. F. WENZEL, *General Dynamics Corporation.*—Azimuthal currents of several thousand amperes moving with high axial velocities have been observed in an electromagnetically driven shock tube. Using a modified conical pinch discharge with a 7.6-cm hollow electrode and a spiral return conductor, ring currents have been observed moving with axial velocities up to $5\times10^6$ cm/sec in a Pyrex cylinder which extends out from the hollow electrode. This current loop has been observed at least 30 cm from the electrode, and is magnetically isolated from the conical discharge. It has an exponential decay time of 3 μsec with an initial pressure of 150 μ of $D_2$. Data correlating the observed signals with the shape of the loop will be presented. Kerr cell pictures of the optical emission show a "doughnut." Momentum transfer to a concentric aluminum ring external to the tube has been observed. Kerr cell pictures will be shown illustrating the optical effects of the interaction of the current loop with an axial magnetic field. Data on the emission spectra will be given for $D_2$ and He.

* This work was done under a contract between General Atomic and the Texas Atomic Energy Research Foundation.

**PA8. Optical Measurements in a Helium Shock Tube.*** H. G. VOORHIES AND F. R. SCOTT, *General Dynamics Corporation.*—Emission of (precursor) light from helium in the triplet state preceding the arrival of the shock front has been observed in a Mach-30 shock tube containing He and a $D_2$-He mixture. Using a 500-mm JACO Ebert monochromator aligned normal to the shock tube axis, the precursor line was observed to be the 5687 A triplet HeI line with a width considerably less than the monochromator resolution. Direct energetic particle excitation was excluded. The proposed explanation is the photo-excitation of the $3^1P$ state with conversion to $3^3D$ by atomic collision and subsequent emission.[1] The line shape of the 5876 A HeI line has been measured in order to determine temperature by Doppler effect. Doppler broadening alone does not account for the line shape.

* This work was done under a contract between General Atomic and the Texas Atomic Energy Research Foundation.
[1] H. S. W. Massey and E. H. S. Burhop, *Electronic and Ionic Impact Phenomena* (Oxford University Press, London, 1952).

**PA9. Experimental Toroidal Discharge Device for Thermonuclear Studies.*** D. F. BROWER AND D. W. KERST, *General Dynamics Corporation.*—The construction of a toroidal discharge device has been completed recently. A somewhat unusual coupling scheme is utilized which permits the use of several comparatively low-voltage capacitor banks to produce a high electric field in the discharge tube. A series of what might be called air core pulse transformers equally divide the necessary flux linkage of the toroidal current. It is designed to operate up to a maximum current of 2.5 Ma with pulse lengths up to several hundred microseconds when crowbarred. The device is "canned" in a heavy copper shield which confines the magnetic field to the immediate vicinity of the torus. The discharge tube has a major diameter of 20 in. and a minor diameter of 3 in. The design of the device and its instrumentation will be described. The possible use of the coupling scheme in an asynchronous high-intensity, low-energy particle accelerator will also be discussed.

* This work was done under a contract between General Atomic and the Texas Atomic Energy Research Foundation.

**PA10. Probe Measurements in a Small Linear Pinch.*** C. L. OXLEY, R. E. DUNAWAY, AND J. H. MALMBERG, *General Dynamics Corporation.*—Measurements have been made with an alumina pinch tube 3 in.×12 in. with 20 kv applied at a central gap. Currents of 100 ka were typical. Axial fields of a few kilogauss were applied. About two joules per cc of deuterium gas in the tube volume were stored in the power supply. Probe coils were inserted in a fixed quartz cross tube. Seven coils were used to read points on a diameter simultaneously. A three-coil probe with two coils connected differentially indicated radial field derivatives. The radial as well as the azimuthal and axial field components were measured. An analysis of the data will be presented.

* This work was done under a contract between General Atomic and the Texas Atomic Energy Research Foundation.

**PA11. Single Particle Trapping in Time Dependent Magnetic Fields.** P. L. AUER AND H. HURWITZ, JR., *General Electric Research Laboratory.*—It has recently been pointed out[1,2] that static radial electric fields enhance the confinement of charged particles in mirror geometry magnetic fields. This result may be viewed as an example of parametric trapping, a phenomenon which follows from the general principle that a system coordinate tends to assume values consistent with the maximization of kinetic energy constrained to exist in other degrees of freedom. Thus, parametric trapping forces may be derived from an effective potential equal to $-T_p$, where $T_p$ is the time average of kinetic energy associated with motions perpendicular to the direction of trapping. In a neutral plasma with an axial magnetic field $B$, the quantity $T_p$ in the small $(m/e)$ limit equals $-\mu B$ plus the rms value of $(m/2)(cEXB/B^2)^2$, where $\mu$ is the adiabatic invariant magnetic moment. An additional asynchronous trapping force proportional to $(\mu/\omega)^2$ exists if the magnetic field gradient oscillates in time with frequency $\omega$. The latter is the magnetic analog of the rf trapping force discussed previously.[3] These results follow from perturbation calculations of single particle orbits or the equivalent macroscopic treatment of dielectric and magnetic polarization forces.

[1] K. Boyer *et al.*, *Second United Nations Conference on Peaceful Uses of Atomic Energy*, A/Conf. 15/P/2383 (June, 1958).
[2] W. R. Baker and S. A. Colgate, reference 2, A/Conf. 15/P/1064 (July, 1958).
[3] H. A. H. Boot *et al.*, J. Elec. Control **4**, 434 (1958).

**PA12. Experiments on Supersonic Plasma Flow along Magnetic Fields.*** D. M. WETSTONE, D. FINKELSTEIN, M. P. EHRLICH, AND I. LIVINGSTON, *New York University.*—Some preliminary photographic results are given of the interaction of supersonic vacuum spark plasma flows with axial magnetic fields[1] up to twenty kilogauss. Two dimensional confinement up to one meter has been observed; also, the plasma appears to follow diverted field lines, as predicted by theory,[2] where various types of "mirror" geometries are created. Time-of-flight studies revealed bulk plasma velocities in excess of 1 cm/μsec. In addition, the experimental apparatus will be described briefly.

* Research supported by the U. S. Atomic Energy Commission.
[1] Finkelstein, Sawyer, and Stratton, Phys. Fluids **1**, 188 (1958).
H. Grad, Bull. Am. Phys. Soc. Ser. II, **3**, 288 (1958).

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FRIDAY AFTERNOON AT 2:00

Empire Room

(E. BURSTEIN presiding)

### *Invited Papers in Solid-State Physics*

**Q1. Donor and Acceptor Energies in Insulators by Photoelectronic Techniques.** R. H. BUBE, *RCA Laboratories.* (30 min.)

**Q2. Electron-Spin Resonance of Deep-Level Impurities in Germanium and Silicon.** G. W. LUDWIG, *General Electric Research Laboratories.* (30 min.)

**Q3. Microwave Faraday Effect in Antiferromagnetics.** A. M. PORTIS, *University of California, Berkeley.* (30 min.)

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FRIDAY AFTERNOON AT 2:00

Grand Ballroom

(ROBERT SERBER presiding)

### *Invited Papers in Theoretical Physics*

**QA1. Gravitational Waves.** P. A. M. DIRAC, *Cambridge University.* (40 min.)

**QA2. Universal Theory of Weak Interactions.** R. E. MARSHAK, *University of Rochester.* (40 min.)

**QA3. Applications of Dispersion Relations to Problems in Particle Physics.** M. L. GOLDBERGER, *Princeton University.* (40 min.)

FRIDAY AFTERNOON AT 2:00

Panel Room

(G. N. GLASOE presiding)

## *Neutron Spectroscopy II*

**R1. Total Cross Sections in the Kilovolt Region by Time-of-Flight.** P. D. MILLER, W. M. GOOD, J. H. GIBBONS, AND J. H. NEILER, *Oak Ridge National Laboratory.*—During a recent total cross section run, $Sc^{45}$, $V^{51}$, $Fe^{57}$, $Co^{59}$, $Cu^{63}$, $Zn^{66}$, $Zn^{68}$, $Ge^{70}$, $Ge^{72}$, $Ge^{74}$, and $Ge^{76}$ were studied in the region from 3 to 30 kv. A number of new resonances were observed, isotopic assignments were made, and previously unresolved levels were split. Energies at the peak cross sections of some of the most prominent of these resonances are given in Table I.

TABLE I.

| Sample | $E_0$ (kev) |
|---|---|
| $Sc^{45}$ | 3.25, 4.26, 6.59, 8.0, 9, 12, 22, 24, 30, 32 |
| $V^{51}$ | 6.5 |
| $Fe^{57}$ | 3.9, 6.1 |
| $Co^{59}$ | 4.9, 8.0, 10, 17, 22, 23, 26, 30 |
| $Cu^{63}$ | 5.28, 7.7, 10, 20, 21, 23 |
| $Zn^{66}$ | 10, 14, 18 |
| $Zn^{68}$ | 18 |
| $Ge^{70}$ | 3.3, 5.6, 6.2, 7, 8, 10, 13 |
| $Ge^{72}$ | 4.9, 9, 12 |
| $Ge^{74}$ | 4.88, 20 |
| $Ge^{76}$ | 4.9, 22, 25, 29 |

**R2. Distribution of the Level Spacings and Neutron Widths of $Al^{28}$.*** CARL T. HIBDON, *Argonne National Laboratory.*—The neutron total cross section from about 1 to 450 kev shows the presence of 66 peaks whose neutron widths vary from 1 to 7 kev.[1] The reduced widths $\gamma^2=\Gamma_n/(2P_l)$ fluctuate rather violently among these levels but appear to agree with the distribution $33\exp(-X)$ and also fairly well with the Porter-Thomas distribution $17X^{-\frac{1}{2}}\exp(-X/2)$ but less well or not at all with other simple proposed distributions. The quantity $X=\gamma^2/(\gamma^2)_{Av}$ is evaluated for a particular $J$ and $l$. A plot of the percentages of levels with widths smaller than a particular value of $X$ compared with plots of the integrals

$$\int_0^x \exp(-X)dX \quad \text{and} \quad \int_0^x X^{-\frac{1}{2}}\exp(-X/2)dX$$

shows that the exponential distribution lies between the data and the Porter-Thomas distribution for small values of $X$ but each distribution approaches the experimental points as $X$ increases. The level spacings appear to agree with the distribution $28\exp(-s)$ but do not appear to agree with the Wigner surmise, $\pi(s/2)\exp(-\pi s^2/4)$, where $s=S/D$ with $S$ the level spacing and $D$ the average spacing for a particular $J$ and parity. A plot of the percentages of spacings smaller than a particular value of $s$ follows the general trend of the integral $\int_0^s \exp(-s)ds$ but is well above the integral

$$(\pi/2)\int^s s\exp(-\pi s^2/4)ds.$$

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] C. T. Hibdon, Bull. Am. Phys. Soc. Ser. II. 2, 232, 354 (1957); 3, 48 (1958).

**R3. Analysis of Neutron Total Cross-Section Data.*** KAMAL K. SETH AND H. W. NEWSON, *Duke University.*—Some recent improvements in methods of analysis of neutron total cross section data, both for individual resonance parameters and for average parameters $R'$ and $\langle\Gamma_n^0/D\rangle$ are presented. The method of area analysis of resonances including the interference effects between resonance and potential scattering has been developed to permit analysis of resonances in the kev region and resonances observed with very thick samples in the ev region of neutron energy. For the cases for which $(R'/\lambda)\approx\pi/4$ resonances antisymmetric about the resonance energy are predicted. For such resonances a new method of analysis depending on algebraic subtraction of area for $E\langle E_0$ from that for $E\rangle E_0$ has been developed. Examples of analysis of resonances in bismuth and strontium using this method are presented. $s$- and $p$-wave resonances are distinguished by these methods of analysis and spins identified in favorable cases. The methods are extended to the determination of the $s$ and $p$ wave $\langle\Gamma_n^0/D\rangle$ and $R'$ from average cross-section data. Illustrative examples are presented for average transmission analysis of titanium and arsenic.

* Work supported in part by the U. S. Atomic Energy Commission.

**R4. Recent Total Neutron Cross Sections for Li, N, C, Cl, Co, Sr, and Pb.*** E. G. BILPUCH, L. W. WESTON, C. D. BOWMAN, AND H. W. NEWSON, *Duke University.*—The total neutron cross sections for natural Li, N, C, Cl, Co, Sr, and Pb have been measured with the 160° collimation-detection apparatus previously described. Li (10 to 155 kev), N (10 to 200 kev), and C (150 to 200 kev) were measured with high resolution, and these elements show no structure in the energy region indicated. For Co in the region 1 to 20 kev we observed 8 resonances which indicate a resonance spacing of 2.5 kev. Hence in our energy interval (5 to 120 kev) we would expect to see about 46 resonances. At least 40 resonances are indicated from our experimental work. In the case of Sr we observed 16 resonances in the region 10 to 200 kev. Four of these resonances are definitely $s$ wave. The remaining 12 resonances have been analyzed by the area and peak-height methods and have been assigned to $p$-wave neutrons. If the level spacing goes as $2J+1$, then we would expect to see 12 $p$-wave resonances in this region. This is what we observe. In the case of natural Pb (10 to 150 kev) we observed all the resonances previously found in separated isotope work reported by this laboratory. In addition we observed eight resonances that have previously been missed because of poorer resolution.

* Supported in part by the U. S. Atomic Energy Commission.

**R5. Properties of Li and LiF Targets.*** L. W. WESTON, E. G. BILPUCH, AND H. W. NEWSON, *Duke University.*—Li and LiF targets have been studied by means of the forward threshold of the Li$(p,n)$ reaction. It has been found that a broad $2^-(l=0)$ resonance at approximately 1.9 Mev, which has been previously studied, accounts for the neutron intensity up to at least 1.92 Mev for a thick target. With a comparison of such a calculated yield and an experimental thick target yield, an accurate value of the average proton energy which corresponds to the neutron threshold can be determined. Agreement is good in the region of proton energy where protons do not leave the target with energy greater than neutron threshold, and at proton energies which are several average target thicknesses above threshold. Nonuniformity of thin Li targets makes them about 1½ times thicker than the energy difference between threshold and peak neutron intensity and limits the resolution that can be obtained to about 900 ev. A reasonably accurate value for average target thickness can be obtained by area analysis of the forward threshold or by careful intensity

measurements at energies far from threshold. Other properties of Li and LiF targets will be discussed.

* Supported in part by the U. S. Atomic Energy Commission.

**R6. Neutron Cross-Section Measurements by the Self-Indication Technique.*** A. YOKOSAWA,† C. KIMBALL,‡ J. MONAHAN, AND F. P. MOORING, *Argonne National Laboratory.*—Two similarly constructed detection systems observe neutrons at equal polar angles (30°) with respect to the incident proton beam from the Argonne electrostatic generator. One system serves as a monitor, the other as the counter. The neutrons which are detected are those which a detector sample scatters into an array of $BF_3$ proportional counters immersed in an oil moderator. At a given neutron energy, three sets of measurements are made. The sets, each consisting of 18 combinations of transmission and detector sample thicknesses, are (1) carbons as both transmission and detector sample, (2) transmission sample of the element $Z$ and detector sample of carbon, and (3) element $Z$ for both transmission and detector samples. Results of a least-squares analysis for the total cross section of C and for the total and absorption cross sections of Au and Sn in the energy range from 300 to 500 kev will be discussed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
† Permanent address: Illinois State Normal University.
‡ Graduate student, Saint Louis University.

**R7. Analysis of Self-Indication Measurements of Neutron Cross Sections.*** C. KIMBALL,† J. MONAHAN, AND F. P. MOORING, *Argonne National Laboratory.*—A new counting system makes possible precision ($\sim$0.5%) measurements of neutron cross sections on a routine basis. The number of counts, normalized to a monitor and corrected for background, for a transmission sample of element $Z$ of thickness $N_a{}^s$ and a detector sample $Z'$ of thickness $M_\beta{}^{s'}$ is given by $C_{\alpha\beta}{}^{ss'} = K_s\langle\exp(-N_a{}^s\sigma_{ts})\times[1-\exp(M_\beta{}^{s'}\sigma_{ts'})]\langle\sigma_{ss'}/\sigma_{ts'}\rangle\rangle$, where the $K_s = \Sigma_l(\omega_l{}^{s'}/4\pi)\times\int_{4\pi}d\Omega\epsilon(\Omega)P_l(\mu)$ and $\omega_l{}^{s'}$ are coefficients in an expansion of the differential scattering cross section $\sigma_{ss}(\Omega)$ in terms of Legendre polynomials $P_l(\mu)$, $\langle x\rangle = \int\phi x dE/\int\phi dE$, $\phi$ is the flux, $\sigma_{ts}$ and $\sigma_{ss}$ are the total and scattering cross sections, and $\epsilon(\Omega)$ is the efficiency of the counting system. At each neutron energy the equations corresponding to 54 combinations of sample thickness are linearized in terms of $K_s$, $\langle\sigma_{ts}\rangle$, $\langle\sigma_{ts}\rangle$, $\langle\langle(\sigma_{ts}-\sigma_{ss})/\sigma_{ts}\rangle$, and $\langle\langle(\sigma_{ts}-\langle\sigma_{ts}\rangle)^2\rangle$, and are solved by an adaptation of the Newton-Raphson method of iteration applied to a least-squares analysis. Results of C, Mo, Ag, and Bi will be discussed for neutron energies from 100 to 300 kev.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
† Graduate student, Saint Louis University.

**R8. Neutron Absorption Cross Sections at 27 kev.** H. W. SCHMITT, J. H. GIBBONS, AND C. N. INSKEEP, *Oak Ridge National Laboratory.*—The neutron absorption cross section has been measured at 27 kev for several elements using a spherical shell transmission method. Neutrons were obtained from a source consisting of a solid antimony sphere encased in a thin (0.030 in.) spherical beryllium shell. Average neutron energy from this source was 27 kev; the spread was 3-kev full width at half-maximum. The neutron detector was a modified long counter, shielded from source gamma rays by lead; this entire assembly was positioned at a distance from the source large compared to the sample shell diameters. A serious attempt was made to maintain "good geometry" in these measurements and corrections for finite source size, finite source-to-detector distance, etc., were minimized, evaluated, and taken into account. Multiple scattering in the sample shells was evaluated according to the method of Bethe, Beyster, and Carter.[1] Preliminary absorption cross sections for elements measured thus far are as follows: silver, 940±70 mb; gold, 520±100 mb; antimony, 500±100 mb; lead, 10±20 mb.

[1] Bethe, Beyster, and Carter, Rept. LA-1429, 1955.

**R9. Gamma Detection of Kilovolt Neutron Capture. I.** J. H. NEILER, R. L. MACKLIN, J. H. GIBBONS, AND P. D. MILLER, *Oak Ridge National Laboratory.*—A 1-m diameter liquid scintillator tank has been constructed and used with the ORNL 3-Mv pulsed Van de Graaff accelerator. Over-all time resolution is 15–20 mμsec. Energy resolution on a single gamma-ray peak is 25–30%. Using "kinematically collimated" neutrons from the $Li^7(p,n)$ reaction (29-kev peak intensity, 17-kev full width at half-maximum) the radiative capture cross sections for a number of elements have been compared. Absolute cross sections have been assigned by normalization to the absorption cross section of Ag as measured by shell transmission at 27 kev[1] (Sb-Be neutrons). Pulse-height spectra in the scintillator have been studied for neutron capture in nineteen of the elements studied. Conversion of the full binding energy to a light pulse, even with over 40 cm of gamma absorption path in the scintillator, seems to be relatively rare. The spectra are sufficiently characteristic, however, to identify neutron binding energies. Values of 6.5±0.4 Mev for $Tb^{159}$ and 6.2±0.4 Mev for $Ho^{165}$ were found in this way.

[1] H. W. Schmitt and J. H. Gibbons (unpublished, 1958).

**R10. Gamma Detection of Kilovolt Neutron Capture. II.** R. L. MACKLIN, J. H. NEILER, J. H. GIBBONS, AND P. D. MILLER, *Oak Ridge National Laboratory.*—The flat response $4\pi$ graphite sphere neutron detector[1] has been used to establish the absolute neutron flux used in the capture cross-section experiments described in the preceding paper. This was accomplished by measuring the 54-min beta activity induced in indium samples. A ZrT target was also used to provide a collimated beam of neutrons from the $T(p,n)$ reaction, of average energy 63 kev (full width at half-maximum 40 kev). Relying on the uniform response of the neutron detector, the 29-kev absolute cross sections were extended to this energy. Comparison of the direct capture gamma cross sections with shell transmission and with activation results shows agreement in many instances but disagreement in a few cases.

[1] R. L. Macklin, Nuclear Instr. 1, 335 (1957).

**R11. Fast-Neutron Capture Cross Sections.*** S. M. AUSTIN, M. G. SILBERT, D. B. FOSSAN, AND W. E. WILSON, *University of Wisconsin.*—Previous measurements[1] of fast-neutron activation cross sections have been extended to higher energies. Cross sections have been measured as a function of energy for $Cu^{65}$, $Br^{79}$ (to 18-$m$ state), $Mo^{100}$, $In^{115}$ (to 54-$m$ state), $I^{127}$, and $Sm^{154}$ in the neutron energy range of 2.6 to 6.2 Mev with neutron energy spreads of 300 to 400 kev. In addition, activation cross sections for $Mn^{55}$, $As^{75}$, $Dy^{164}$, $Ho^{165}$ (to 27.2-$h$ state), $W^{186}$, and $Au^{197}$ were obtained at 5.5 Mev. The $D(d,n)He^3$ reaction served as the neutron source. The activity induced by fast neutrons was measured and compared to that induced by thermal neutrons. The fast and thermal fluxes were compared with a $U^{235}$ fission counter. All of the cross sections measured decrease monotonically in this energy region. The $I^{127}$ cross section varies from 30 mb at 2.7 Mev to 5 mb at 6.2 Mev.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
[1] Johnsrud, Silbert, and Barschall, Bull. Am. Phys. Soc. Ser. II, 3, 165 (1958); M. G. Silbert and A. E. Johnsrud, Bull. Am. Phys. Soc. Ser. II, 3, 364 (1958).

**R12. Multiple Neutron Capture in the Mike Fusion Explosion.** A. G. W. CAMERON, *Atomic Energy of Canada, Ltd.*—The constant ratio of yields of successive even or odd mass

number nuclides produced in the Mike fusion explosion of 1952 implies that neutron-rich uranium isotopes have an approximate constancy of average neutron capture cross sections near 100 kev neutron energy. This in turn implies that $\Gamma_\gamma/D_0$ is approximately constant in these nuclei, where $\Gamma_\gamma$ is the radiation width and $D_0$ is the spacing of levels of zero spin near the radiating level. From the theory of radiation widths it follows that the quantity $I=\int_0^U dEE^2/D_0(U-E)$ is approximately constant, where $E$ is the energy of the radiated photon and $U$ is an effective excitation energy equal to the neutron binding energy plus 100 kev minus the particle pairing energies. Conventional mass formulas predict that $U$ decreases by nearly a factor 2 in the range $U^{238}$ to $U^{254}$. If this were correct, it would require a very unreasonable behavior of $D_0$ to maintain constancy of the quantity $I$. It is therefore concluded that the conventional mass formulas are wrong and that neutron binding energies are nearly constant in the range $U^{238}$ to $U^{254}$. An increased diffuseness of the nuclear surface in these nuclei may produce this effect by lowering the nuclear Coulomb energy.

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FRIDAY AFTERNOON AT 2:15

Terrace Room

(D. M. DENNISON presiding)

**RA1. Soviet Polymer Science.** HERMANN MARK, *Polytechnic Institute of Brooklyn.* (30 min.)
**RA2. Field-Induced Absorption in Hydrogen.** M. F. CRAWFORD, *University of Toronto.* (30 min.)
**RA3. Infrared Spectrum of Solid Hydrogen.** ELIZABETH J. ALLIN, *University of Toronto.* (30 min.)
**RA4. Exciton Theory of the Infrared Spectrum of Solid Hydrogen.** J. VAN KRANENDONK, *University of Toronto.* (30 min.)

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FRIDAY AFTERNOON AT 2:15

Boston Room

(J. W. M. DUMOND presiding)

## *Electron Physics*

**S1. Optical Constants and the Low-Lying Characteristic Energy Loss in Aluminum.** H. MENDLOWITZ, *National Bureau of Standards.*—Many investigators[1] have found, that in addition to the prominent characteristic energy loss in aluminum at about 15 ev, there is a low-lying characteristic loss at about 7 ev. Although the predominant 15 ev loss could be attributed to the excitation of collective oscillations of the "free electrons" in the material (when the number of free electrons per atom in aluminum is taken to be three), the low-lying loss could not be explained on this basis. It has been suggested that the low-lying loss may arise from surface polarization effects on the free electron gas in the metal.[2] Others have suggested that the low-lying loss may be due to carbon contamination of the target foils in the dynamic vacuum system, and that one actually observes a characteristic loss in carbon. We will show that these assumptions are untenable, and will demonstrate that both the low-lying loss as well as the predominant loss can be explained in terms of the frequency dependence of the dielectric constant as we had suggested earlier.[1] These data will be correlated with recent data on the optical constants of aluminum in the near and far ultraviolet.

[1] Marton, Leder, and Mendlowitz, *Advances in Electronics and Electron Physics* (Academic Press, New York 1945), Vol. 7, p. 83.
[2] R. H. Ritchie, Phys. Rev. **106**, 874 (1957); E. A. Stern and R. A. Ferrell, Bull. Am. Phys. Soc. Ser. II, **3**, 191 (1958).

**S2. Characteristic Energy Losses of Electrons in Sodium and Potassium.*** M. D. WAGNER, J. A. SUDDETH, J. AROL SIMPSON, AND L. MARTON, *National Bureau of Standards.*—The energy spectrum of 20 kev electrons scattered by sodium and potassium has been remeasured. Both spectra have a previously unreported low-lying loss (Na: 3.1 ev, K: 3.7 ev). The existence of these losses was anticipated by earlier work[1,2] and by optical data.[3] Both losses disappear after a few minutes of electron bombardment in a liquid nitrogen trapped dynamic vacuum. Electron diffraction studies show that the disappearance is probably due to the formation of the hydroxide. The Na to be investigated was deposited upon a number of substrate materials, and the energy spectra measured before and after annealing. The preponderance of evidence argues against the hypothesis of surface polarization causing the low-lying loss.

* This research was supported in part by the U. S. Atomic Energy Commission.
[1] L. B. Leder, Phys. Rev. **103**, 1721 (1956).
[2] Leder, Mendlowitz, and Marton, Phys. Rev. **101**, 1460 (1956).
[3] H. E. Ives and H. B. Briggs, Phys. Rev. **26**, 238 (1936); *ibid.* **27**, 181 (1937).

**S3. Energy Loss of Heavy Ions in Aluminum.*** L. C. NORTHCLIFFE, *Yale University.*—Range-energy relations for heavy ions in aluminum have been obtained by passing magnetically analyzed ion beams from the Yale heavy ion linear accelerator through stacked aluminum foils of measured thickness and determining the momentum of the emergent ions. The momentum measurement was made by collimating the ions, deflecting them in a known magnetic field, and detecting them on a strip of photographic film. A line spectrum resulted, each line corresponding to a unique value of the momentum to charge ratio of the detected ions. Since the ion charge could be inferred from the separation of adjacent lines the ion momentum could be determined unambiguously from the total deflection. An accurate scale was printed on the film at the time of the exposure and more than 100 exposures could be made without breaking vacuum. With this equipment the range-energy relations for $He^4$, $C^{13}$, $N^{14}$, and $O^{16}$ ions in aluminum were measured in the energy region between 1 and 10 Mev per nucleon with an estimated accuracy of about one percent.

* This work was supported by the U. S. Atomic Energy Commission.

**S4. Direct Observation of Surface Catalyzed Production of Hydrocarbons from Elements.** GEORGE E. MOORE, *Bell Telephone Laboratories.*—On heating an auxiliary carbon-containing molybdenum filament in a mass spectrometer operating in hydrogen at $10^{-6}$ to $10^{-5}$ mm pressure, hydrocarbon molecules and free methyl radicals leave the molybdenum surface. Ethylene (possibly ethylidene) is much the most abundant product, but hydrocarbons through the $C_3$ series are readily observed. One distinguishes fragments from true products by using ionizing electrons of energy below fragmentation thresholds. Although somewhat similar experiments have been[1,2] described, direct observation by mass spectrometer of hydrocarbon molecules and radicals as produced from their elements by surface catalysis has apparently not been reported. Fundamental comparison of surfaces for catalyzing hydrogenation and other reactions may be possible by this method. Hickmott and Ehrlich,[3] using an omegatron, believed that CO was produced on desorbing hydrogen from tungsten. Ethylene and CO have the same mass; ethylene produced as described in the foregoing may offer a simpler explanation for their result than CO.

[1] G. C. Eltenton, J. Chem. Phys. **15**, 455 (1947).
[2] P. LeGoff and M. Letort, J. chim. phys. **54**, 3 (1957).
[3] T. W. Hickmott and G. Ehrlich, J. Phys. Chem. Solids **5**, 57, 1958.

**S5. On J. J. Thomson's Classical Formula for Ionization.** EUGENE GUTH, *Oak Ridge National Laboratory.*—Mott and Massey[1] comment on the very different form of the classical (J. J. Thomson) and quantal (Bethe) expressions for (primary) ionization; in particular, the Thomson formula contains no logarithmic term, while the Bethe formula does. According to Williams and Terroux[2] for hydrogen at $v/c=0.54$ and NTP Bethe's formula gives four times as many ions produced per cm path as J. J. Thomson's, while the experimental value is about 15% lower than Bethe's. For ionization, just as for stopping, the total effect consists of the sum of contributions due to close (free) and distant (resonance) collisions. J. J. Thomson in his *classic paper*[3] *took account only of the close collisions. The distant collisions, however, bring in a logarithmic term increasing the ionization and decreasing the gap between theory and experiment.* Just as for the case of stopping power, the close collisions are treated classically and quantally the same, while for the distant collisions the quantal (Born) treatment implies a perturbation method; in the classical treatment no perturbation treatment is used.

[1] Mott and Massey, *The Theory of Atomic Collisions* (Oxford University Press, Inc.), second edition, p. 247.
[2] Williams and Terroux, Proc. Roy. Soc. (London) **A289**, 126 (1930).
[3] J. J. Thomson, Phil. Mag. (6) **23**, 449 (1912).

**S6. Electron Drift Mobility in Liquid *n*-Hexane.** OLIVER H. LEBLANC, JR., *General Electric Research Laboratory.*—The drift mobility of electrons in liquid *n*-hexane has been measured using a new experimental technique. Electrons are injected into the liquid from a photosensitive cathode by a pulse of ultraviolet light whose duration is short compared to the carrier transit time. The drift of the negative carrier pulse to the anode produces a transient current in the external circuit from which the transit time is readily obtained. Measurements were carried out at field strengths below 2 kv/cm and over the temperature range $-47$ to $+27$°C. The data are represented by $\mu=\mu_0 \exp(-\Delta\epsilon/kT)$, where $\mu_0=0.3$ cm²/v-sec and $\Delta\epsilon=0.14$ ev. These results indicate that the current carrier is neither a free electron nor a negative molecular ion. It is proposed that the carrier is an electron whose drift is modulated by shallow traps of 0.14 ev average depth.

**S7. Structure in the Energy Distribution of Photoelectrons from $K_3Sb$ and $Cs_3Sb$.** E. A. TAFT AND H. R. PHILIPP, *General Electric Research Laboratory.*—In the optical absorption of $K_3Sb$, Spicer has found two pronounced peaks.[1] We corroborate his result. At higher energy, $h\nu>4$ ev, there appears further structure of a similar type. At 80°K, these absorption peaks sharpen and reveal substructure. Corresponding structure shows up in the energy distribution of photoelectrons. Structure in the state density of the valence band is a conceivable source of these effects. This offers a new approach for determining a lower limit to the electron affinity of the crystal. A value so determined for $K_3Sb$ is 0.6 ev. Similar but less pronounced effects occur in $Cs_3Sb$ and other related compounds.

[1] W. E. Spicer, Phys. Rev. (to be published).

**S8. Electroluminescence in Single Crystals of GaP.** E. E. LOEBNER AND E. W. POOR, JR., *RCA Laboratories.*—Electroluminescence in polycrystalline GaP has been observed by several workers.[1,2] However they were unable to determine its origin as has been done for Ge, Si, GaAs, and SiC. I. Hegyi of our laboratories has grown single crystals for GaP which show rectifier-type electroluminescence similar to SiC. Reverse-biased GaP rectifiers emit a broad spectrum peaking at 0.62 $\mu$, extending beyond 1.2 $\mu$, and exhibiting a sharp cutoff at 0.52 $\mu$ due to self-absorption. Light escaping from several spots near the surface contains photons with energies larger than the band gap. Forward-biased GaP rectifiers emit a symmetrical spectral band peaking at 0.9 $\mu$ and about 0.5 $\mu$ wide. The light is proportional to the current; cases of no current-threshold have been demonstrated. We conclude the former phenomenon to be due to electron avalanches. The latter is most likely associated with hole injection into the *n*-type bulk of GaP with recombination taking place through a Cu center.

[1] Wolff, Herbert, and Broder, Phys. Rev. **100**, 1144 (1955).
[2] Holt, Alfrey, and Wiggins, Nature **181**, 109 (1958).

**S9. Mechanical Stimulation of Edge Emission in Cadmium Sulfide.** C. H. BLAKEWOOD, D. M. WARSCHAUER, AND D. C. REYNOLDS, *Aeronautical Research Laboratory.*—Green luminescence has been observed when ultraviolet stimulated CdS at liquid $N_2$ temperature is mechanically tapped parallel to the $C$ axis after removal of the ultraviolet. The light, verified to be edge emission, occurs in streamers running from the point of impact in a direction parallel to the $C$ axis. Tapping perpendicular to the $C$ axis produces no emission. The effect, which is observed in both pure and Ag doped synthetic crystals, is associated with a persistence of conductivity at liquid nitrogen temperature after stimulation. Silver-doped crystals exhibit red emission on tapping which masks a green component that is present. Glow curve studies indicate that the process associated with red emission in these crystals can be exhausted without greatly impairing the green storage. Spectral emission, conductivity, and quenching studies suggest that this phenomenon can be explained by invoking a model employing mechanically stimulated hole traps.

**S10. Afterglow of Chlorophyll.*** H. O. ALBRECHT AND C. E. MANDEVILLE, *Bartol Research Foundation,* AND W. C. DENISON AND L. G. LIVINGSTON, *Swarthmore College.*—In the course of investigating low level light emission from biological materials, the afterglow of chlorophyll has been studied. The effects of various conditions and agents upon chlorella suspensions and those of chloroplasts of spinach suggest a more nearly "physical" explanation for the long-lived phosphorescent emission of chlorophyll than is presently current. While photosynthesis and afterglow are observed under either blue or red illumination, the afterglow induced by blue irradiation is "quenched" when blue and red are applied simultaneously. An artificial phosphor containing chlorophyll and giving a long-lived afterglow will be discussed.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

FRIDAY AFTERNOON AT 2:00

Governor Clinton Hotel

(A. S. NOWICK presiding)

## *Metals; Dislocations; Radiation Damage*

**SA1.** (Abstract withdrawn.)

**SA2. Phase Diagram of Rubidium to 150 000 kg/cm² and 500°C.** F. P. BUNDY, *General Electric Research Laboratory.*—At room temperature rubidium shows a sharp reversible phase transition at about 107 000 kg/cm². This transition is nearly independent of temperature. The melting point goes from about 39°C at atmospheric pressure to about 280°C at 17 500 kg/cm² where there appears to be a triple point for two solid phases and the liquid. The boundary between the high- and low-temperature solid phases extends to another triple point at about 190°C, 107 000 kg/cm², and continues on with decreasing temperature for higher pressures. No "resistance cusp" transition like that for cesium at 55 000 kg/cm² appears up to 150 000 kg/cm². All observations were based on electrical resistance of a rubidium wire. No measurements of volume changes were made so that any phase transitions involving volume changes without change of electrical resistance would not have been observed.

**SA3. Ultraviolet Transparent Alkali Metal Filters.*** W. T. FOREMAN AND C. H. SHAW,† *Baird-Atomic, Inc.*—More or less uniform cells of ultraviolet transparent fused quartz about one micron thick and over two inches in diameter have been produced and filled with sodium-potassium alloy, which is liquid at room temperature. These filters, while opaque in the visible, are transparent in the ultraviolet, with a cutoff wavelength lying between that for pure sodium (2100 A) and pure potassium (3400 A) and determined by the alloy composition. A tentative formula for the calculation of the cutoff wavelength is proposed and tested. The optical constants for the alloy were determined and are compared with those of the pure metals and with Kronig's theory.

* Supported by a U. S. Navy contract.
† Permanent address: Ohio State University.

**SA4. Low Temperature Optical Absorption in α-Brasses.** J. A. RAYNE AND M. A. BIONDI, *Westinghouse Research Laboratories.*—Optical absorption studies have been made at liquid helium temperatures on a representative series of α-brasses in the region 0.23 to 4.0 microns. Measurements were made calorimetrically on electropolished specimens, luminous energy being obtained from a grating monochromator. The variation with residual resistance of the infrared absorptivity of the alloys is analyzed to provide information concerning the optical effective mass in copper. The changes in the absorption structure, occurring at wavelengths shorter than 0.6 microns, are examined in the light of present theory concerning the electronic structure of such alloys.

**SA5. Optical Properties of Tungsten.** S. ROBERTS, *General Electric Research Laboratory.*—Optical properties of a ribbon of pure tungsten have been measured at room temperature and at elevated temperatures by a modification of Drude's classical method based on the techniques of Beattie[1] and Hodgson.[2] The real and imaginary parts of the dielectric constant are reported in a wavelength range from 0.36 to 2.65 microns at temperatures 298, 1100, and 1600°K. The real part is positive below about 0.9 micron and is a rapidly growing negative quantity as wavelength increases above this point. The imaginary part fluctuates between about 20 and 30 at 298°K. At higher temperatures it rises to about 100 at 2.65 microns. Emissivities calculated from these data are in reasonably good agreement with the results of DeVos[3] and indicate an $x$ point at 1.13 micron as compared with his value of 1.27.

[1] J. R. Beattie, Phil. Mag. **46**, 235 (1955).
[2] J. N. Hodgson, Proc. Phys. Soc. (London) **B68**, 593 (1955).
[3] C. DeVos, Physica **20**, 690 (1954).

**SA6. Nature of Absorption Edge Electron Transitions in β-Brass Alloys.*** L. MULDAWER, *Temple University.*—Spectral reflectivity measurements at room temperature of β-brass alloys show a shift of the edge to lower energy with increasing zinc content. A similar effect is seen in β-AgCd Alloys. This indicates the operation of an electron transition from the top of the Fermi sea to an upper band and not from the underlying $d$ band to the surface of the Fermi sea. The latter is the responsible mechanism in the α-brasses. The observed reflectivity edge shift in β-brass is −0.031 ev/%Zn. A simple calculation assuming only electron-atom ratio and lattice parameter changes gives a Fermi level shift of +0.029 ev/%Zn; this is in good agreement with the above scheme providing the electron band structure undergoes negligible changes.

* Supported by the U. S. Air Force Office of Scientific Research.

**SA7. Evidence of Phonon Drag in Metals.*** R. H. KROPSCHOT† AND F. J. BLATT, *Michigan State University.*—We have measured the thermoelectric power of pure copper (99.999%) relative to the following dilute copper alloys (approx. 1% solute): CuZn, CuGe, CuCd, CuIn, CuSn, and CuSb. The measurements extended over the temperature range between 4°K and 350°K. We attempted to fit our results to the Friedel formula[1] for the change in thermoelectric power due to allowing $\Delta S = -S_0(1-\Delta x/x)/(1+\rho/\Delta\rho)$, in which the parameter $\Delta x$ should be temperature independent, but were unable to obtain a satisfactory fit to that equation. However, if reasonable assumptions are made concerning the phonon-drag contribution to the thermoelectric power of pure copper, all our data show internal consistency and can be interpreted by means of the Friedel formula, using one temperature-

independent parameter $\Delta x$ for each alloy. The results show that as a result of isotope scattering of phonons the phonon-drag effect is greatly reduced in the alloys CuCd, CuIn, CuSn, and CuSb, but, as expected, remains unaffected in CuZn and CuGe. The magnitude and temperature dependence of the phonon-drag contribution to the thermoelectric power of pure copper which we deduce from our measurements are in good agreement with theoretical estimates.[3]

* Supported in part by the Office of Ordnance Research, U. S. Army.
† Present address: National Bureau of Standards, Boulder, Colorado.
[1] J. Friedel, Advances in Phys. 3, 446 (1954).
[2] I. I. Hanna and E. H. Sondheimer, Proc. Roy. Soc. (London) A239, 247 (1957).

**SA8. Light Scattering by Charged Dislocations in Ionic Crystals.*** C. A. PLINT AND O. THEIMER, *University of Oklahoma.*—The temperature dependence of light scattering by single crystals of sodium chloride, potassium chloride, and potassium bromide has been investigated in the temperature region 168°K to 350°K. Pronounced maxima and minima of the scattering power are observed. The results will be discussed in terms of vacancy and impurity clouds surrounding charged dislocations. Experimental methods will be described.

* Work supported by the Office of Ordnance Research, U. S. Army.

**SA9. Light Scattering by Dislocation Networks in Single Crystals of Potassium Chloride.*** O. THEIMER AND C. A. PLINT, *University of Oklahoma.*—Light scattering by single crystals of Harshaw potassium chloride was measured for different scattering angles and different orientations of the crystal with respect to the direction of the incident light beam. It was found that the scattering system has a fourfold axis of symmetry but apparently no plane of symmetry. A partial, two-dimensional Fourier analysis of the scattering power suggests that the scattering is produced by rectangular networks of "rods" with rod width between 1000 and 2000 A, and mesh width of about 10 000 A. The absence of a plane of symmetry suggests that the rods are edge dislocations surrounded by clouds of vacancies and impurities with concentrations varying from the compression to the dilation side of the dislocations.

* Work supported by the Office of Ordnance Research, U. S. Army.

**SA10. Thermoelastic and Dislocation Damping in Polycrystalline Aluminum at Low Temperatures.** D. H. ROGERS, A. J. FILMER, AND T. S. HUTCHISON, *Royal Military College of Canada.*—Internal friction measurements at 40 kc on well-annealed polycrystalline aluminum at temperatures between 4°K and 300°K are described. It is suggested that two mechanisms account for the damping at very low temperatures. These are (a) damping by dislocation movement and (b) thermoelastic damping resulting from minute thermal currents across the grain boundaries. Mechanism (a) is indicated by an amplitude dependence of internal friction which exists even at 4°K. This amplitude dependence is itself temperature dependent. Mechanism (b) is apparent if the dislocation density is reduced sufficiently by annealing, i.e., so that the decrement is of the order of $10^{-6}$. The internal friction results then show a minimum at about 40°K. The increase below that temperature resulting from a rapid rise in diffusivity is in agreement with the Zener thermoelastic theory.

**SA11. Mechanical Properties of Dislocation-Free Silicon Crystals.** W. C. DASH, *General Electric Research Laboratory.*—At 900°C, single crystals of silicon deform readily by a Frank-Read mechanism at stresses of about 1 kg/mm² when dislocations are present.[1] However, plastic deformation does not occur in dislocation-free crystals[2] at stresses over 20 kg/mm² provided that care is exercised in etching and handling the samples. If superficial damage produced during preparation of the samples is not completely removed or if damage is introduced deliberately, deformation occurs at much lower stresses in dislocation-free crystals at 900°C. Carefully etched samples with cross-sectional areas of 0.25 mm² have been bent elastically at room temperature to strains of 2% before fracture. The presence of dislocations does not affect these results. Elastic strains of this magnitude have been reported previously only for whiskers and for specimens cut from bulk silicon, but with 100 times smaller cross-sectional areas. Two conclusions can be drawn from these studies: Silicon crystals in which no dislocations can be detected by decoration and etch pit techniques are much stronger at high temperatures than those in which dislocations are present. The mechanical strength at all temperatures is very sensitive to the condition of the surface.

[1] W. C. Dash, *Dislocations and Mechanical Properties of Crystals* (John Wiley and Sons, Inc., New York, 1957), p. 57.
[2] W. C. Dash, J. Appl. Phys. 29, 228 (1958).

**SA12. Effect of Neutron Irradiation on Thermally and Mechanically Induced Nonequilibrium States in AuCu.** R. L. MCCOLLUM AND G. ALLEN, *Lewis Research Center.*—Specimens of AuCu were subjected to various thermal and mechanical treatments. They were then exposed to integrated thermal neutron fluxes up to $2.2\times10^{19}$ n/cm² in the Brookhaven pile. The effect of the irradiation on thermally disordered specimens was to decrease the resistivity in completely disordered states and to increase the resistivity in completely ordered states; *viz.*, the specimen appeared to reach intermediate degrees of order. The effect on mechanically disordered specimens was to increase the resistivity in all cases. The percentage change in the coefficient of magnetoresistivity $B$ was greater than that of the resistivity $\rho$, but the $B$-$\rho$ relationships remained essentially the same as for unirradiated AuCu which had received a thermal or mechanical treatment leading to equal resistivity.

**SA13. Monoenergetic Neutron Irradiation of Germanium.** O. L. CURTIS, JR., AND J. W. CLELAND, *Oak Ridge National Laboratory.**—Lifetime and carrier concentration measurements have been made on germanium following irradiation by 14-Mev neutrons obtained from a Cockcroft-Walton accelerator, utilizing the $T(d,n)He^4$ reaction. Lifetime changes are observed to be about an order of magnitude larger than for an equal number of fission neutrons. The dependence of lifetime upon temperature and carrier concentration in $n$-type material can be explained satisfactorily on the basis of a one-level recombination center. The energy level associated with this center lies ~0.32 ev above the valence band, or very near the center of the forbidden gap. This is to be compared to a position of 0.20 ev below the conduction band for reactor neutron-induced centers. The cross-section ratio, $\sigma_P/\sigma_N$, equals ~1800, indicating that the center is negatively charged. The analysis of the results of $p$-type material is more complicated. Preliminary measurements of the carrier removal rate indicate about 8 electrons are removed per incident 14-Mev neutron in $n$-type Ge and about one hole added per incident neutron in $p$-type Ge.

* Oak Ridge National Laboratory is operated by Union Carbide Nuclear Company for the U. S. Atomic Energy Commission.

**SA14. Effects of Surfaces and Deformation on Alkali Halides X-Rayed at 5 and 300°K.** HERBERT N. HERSH, *Zenith Radio Corporation.*—In a previous study, compressed polycrystalline pellets of several alkali halides colored by $x$ irradiation at 300°K were shown to exhibit enhanced $V$ bands as compared to single crystals.[1] If x-rayed at 5°K, the $F$ and $H$ bands dominate the absorption spectrum, as in single crystals, but new phenomena occur as well. In the present investigation the effects of surfaces and deformation on x-ray induced color center production at 300 and 5°K are studied, using compressed polycrystalline pellets and compressed *single* crystals of KCl, KBr, and KI. It is shown that

the enhanced $V$ band production at 300°K is essentially a surface phenomenon, as it does not occur in annealed or compressed single crystals. The ratio of the absorption intensities of the $H$ to $F$ bands produced at 5°K is much greater in the pressed polycrystalline pellets than in either the annealed or compressed single crystals. The enhanced $H$ band appears to be due to a surface property. The absorption spectra in the $F$-band region of pellets of KCl and KBr x-rayed at 5°K disclose the presence of electron surplus centers not found in "good" single crystals similarly treated. These centers, unstable at 78°K, are not associated with the surfaces but with deformation, since they are found also in compressed single crystals.

[1] H. N. Hersh, J. Chem. Phys. 27, 1330 (1957).

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FRIDAY EVENING AT 7:00

Terrace Room

(J. W. BEAMS AND C. J. OVERBECK presiding)

***Banquet of the American Physical Society and AAPT***

**Physicists in the National Space Programme.** H. L. DRYDEN, *National Aeronautics and Space Administration.*

"Research into Controlled Fusion." Moving picture issued by the U. S. Atomic Energy Commission.

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SATURDAY MORNING AT 9:30

Empire Room

(K. A. BRUECKNER presiding)

***Theoretical Physics V: Nuclear Theory, Pion Theory***

**T1. Nuclear Matter in the Boundary Condition Model.*** E. L. LOMON, *McGill University.*—Some success has been obtained in the representation of the nucleon-nucleon interaction by means of an energy independent boundary condition for separations of about one fermi. The method is being applied to the many body problem. The relative simplicity of the approximate solution when potentials are avoided may give insight into the sensitivity of the many body problem to the two body parameters. The three body problem has been treated by this method.[1] The infinite nucleus is considered here. The boundary condition is represented by a delta function potential which can be substituted into the Bethe-Goldstone equation. The Pauli term is immediately integrable, when the potential internal to the boundary radius is assumed to vanish. This is an additional assumption; information being required about the near as well as the asymptotic wave function in contrast to the two body problem. The application of the perturbation technique of L. Eyges[2] is also developed.

* Supported in part by a National Research Council (Canada) Research Grant.
[1] L. Eyges (private communication).
[2] L. Eyges, Ann. phys. 2, 101 (1957).

**T2. Application of the Boundary Condition Potential to the Nuclear Many-Body Problem.*** S. A. MOSZKOWSKI AND B. L. SCOTT, *University of California, Los Angeles.*—The nuclear many-body problem has been investigated using as a representation of the nucleon-nucleon force an energy-independent boundary condition at a radius of 0.9 fermi with an attractive well outside. The effect of the boundary condition is to make the two-particle wave function vanish for separations less than 0.9 fermi while leaving it shifted only slightly from the free particle unperturbed wave function for larger distances. The shift vanishes for zero energy. This introduces into the wave function mainly high momentum components which are affected little by the Pauli principle, so that the short-range part of the reaction matrix in nuclear matter differs only slightly from that in free space. This enables one to treat the short-range potential and the attractive well separately as a first approximation, which considerably simplifies the application of the Brueckner technique. The correction terms may be calculated if needed but are small. A preliminary calculation of the nuclear binding energy and equilibrium density for infinite nuclear matter, neglecting these corrections, was made using for the attractive well a force acting in $S$ states only. The results are in good agreement with experiment. The B. C. potential also clearly illustrates the reasons for the validity of the shell model.

* This work was supported in part by the Office of Ordnance Research.

**T3. Correlation Structure of Nuclear Wave Functions.*** H. KÜMMEL, *State University of Iowa* (introduced by F. Coester).—A bound state of a system of many fermions can be described by relating it to a largely arbitrary set of single particle wave functions $u_\nu(x)$. $(x_n \cdots x_1|\psi|\nu_1 \cdots \nu_n)$ is the probability amplitude for finding $n$ particles at the points $x_1 \cdots x_n$ and the remaining particles *not* in the states $\nu_1 \cdots \nu_n$. In the absence of many body forces only $(x|\psi|\nu)$ and $(x'x|\psi|\nu\nu')$ are needed for a rigorous calculation of the energy. The rigorous Schrödinger equation couples these functions to all higher ones. However, if the set of functions $\psi$ has a cluster structure the equations are weakly coupled. In the lowest approximation one obtains modified Brueckner equations first derived by Brenig.[1] The order of magnitude of the correction terms and their dependence on the choice of the $u_\nu$ has been investigated. The Brueckner theory appears as the lowest order approximation of a systematic approximation scheme in terms of powers of $R^3/\Omega$ where $R$ is the "healing distance"[2] and $\Omega$ the nuclear volume. Therefore a rigorous solution of these equations should yield the binding energy of heavy nuclei with an accuracy of about 1%.

* Work supported by the U. S. Atomic Energy Commission.
[1] W. Brenig, Nuclear Phys. 4, 363 (1957).
[2] Gomes, Walecka, and Weisskopf, Ann. Phys. 3, 241 (1958).

**T4. Harmonic Oscillator Wave Functions in Nuclear Spectroscopy.*** R. D. LAWSON, *University of Chicago*, AND M. GOEPPERT MAYER, *Argonne National Laboratory and University of Chicago.*—Pairing energy calculations are generally carried out assuming the nucleon wave functions are those of an harmonic oscillator. The two-body interaction is assumed to be some function of $\sigma_1$, $\sigma_2$ and $\mathbf{r}_1-\mathbf{r}_2$. Since the coordinates appear only in the form $\mathbf{r}_1-\mathbf{r}_2$, it is convenient to write the two-body wave function in terms of the relative coordinate, $\mathbf{r}=\mathbf{r}_1-\mathbf{r}_2$ and the center-of-mass coordinate, $2\mathbf{R}=\mathbf{r}_1+\mathbf{r}_2$. The eigenfunction in the new coordinates is determined by noting that if the two particles are in the same oscillator shell, then $\phi(\mathbf{r}_1,\mathbf{r}_2)$, which is an eigenfunction of $H(\mathbf{r}_1)+H(\mathbf{r}_2)$, is also an eigenfunction of $H(\mathbf{r}_1)$ alone. Transforming $H(\mathbf{r}_1)$ to relative and center-of-mass coordinates implies that the operator $\mathbf{p}\cdot\mathbf{P}+\alpha\mathbf{r}\cdot\mathbf{R}$ (where $\alpha$ is related to the spring constant of the oscillator) must give zero when operating on the wave function. This condition plus certain requirements arising from the radial form of the oscillator eigenfunctions is sufficient to determine the wave function in the new coordinate system.

* Supported in part by the U. S. Atomic Energy Commission.

**T5. Effect of Nuclear Forces on the Cross Sections of Photonuclear Reaction.*** K. OKAMOTE,† *Louisiana State University.*—The effect of nuclear forces, i.e., the effect of the quasideuteron model, on the photonuclear cross sections has been investigated using perturbation theory. The plane wave is used for the unperturbed wave function, and the two body potential is assumed to have partly Majorana exchange character and Gaussian radial dependence. Only the central force is considered and the hard core is neglected. The parameters are taken from the effective range theory. The results are that the integrated cross section is increased by several percent and that the bremsstrahlung weighted cross section is decreased by about the same amount. In other words the independent particle model can be regarded as a good approximation for photonuclear reaction.

* Supported by the Research Corporation.
† Now at McMaster University.

**T6. Spin Orbit Potential of Nucleons.** E. BUTKOV AND E. L. LOMON, *McGill University.*—The Levy-Klein covariant technique is used to calculate, for pseudoscalar coupling, the spin orbit potential of fourth order in the coupling constant, to several orders in the ratio of meson to nucleon mass. Two nucleon-pair graphs give the lowest order term as calculated by Klein.[1] The next order contribution comes from both the one-pair and two-pair graphs. The former contribution is large and is not very different from the phenomenological potential. Its strong singularity makes its average effect sensitive to the cutoff radius. If the mechanism of pair suppression is important the theoretical potential may become too small.[2] The simultaneous effect of pair suppression on the static and spin orbit potentials is being evaluated by including the higher order pair contributions in the static approximation. This will indicate whether the experimentally required suppression of the static pair term necessarily implies an equally strong suppression of the spin orbit term.

[1] A. Klein, Phys. Rev. **90**, 1101 (1953).
[2] S. Okubo and R. E. Marshak, Ann. phys. **4**, 166 (1958).

**T7. Modified Analysis of Nucleon-Nucleon Scattering.*** M. J. MORAVCSIK, P. CZIFFRA, M. H. MACGREGOR, AND H. P. STAPP, *University of California, Livermore and Berkeley.*—Work will be reported on a suggestion[1] to include the Born approximation to the one-pion exchange process explicitly into the nucleon-nucleon scattering amplitude. Since the one-pion exchange has the longest range of the various forces in the nucleon-nucleon interaction, it should determine the contribution in the high angular momentum states. The use of the Born approximation is justified by the study of the location of the singularities in the scattering amplitude.[2] The aim of the modified scheme is to (a) include, at least partially, all the angular momentum states, (b) reduce the number of parameters required to characterize nucleon-nucleon scattering at a given energy, (c) eliminate some of the ambiguity in the conventional phase shift analysis, and (d) determine the pion-nucleon coupling constant. The method has been applied to data on $p$-$p$ scattering at 310 Mev and significant results were obtained which will be presented at the meeting.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] M. J. Moravcsik, UCRL-5317-T (August, 1958).
[2] G. F. Chew, UCRL-8283 (May, 1958).

**T8. High-Energy Nucleon-Nucleus Scattering and Polarization.*** ALAN CROMER, *Cornell University.*—The elastic scattering and polarization of high-energy protons from complex nuclei has been investigated using the direct-interaction model of nuclear reactions. In this model the Born approximation to the proton-nucleus scattered amplitude is just proportional to the nuclear form factor and to the nucleon-nucleon scattered amplitude, averaged over the target nucleons. From it an optical potential can be calculated, which includes the complete angular dependence of the nucleon-nucleon scattered amplitude. Using the nucleon-nucleon scattered amplitudes given by the various phenomenological nucleon-nucleon potentials and nucleon-nucleon phase shift analyses, the cross section and polarization of protons scattered by light nuclei has been calculated at several energies. The agreement with experiment obtained indicates that high-energy nucleon-nucleus scattering can be understood quantitatively in terms of the nucleon-nucleon interaction, and that the study of such reactions can give information about this interaction. In particular, it may be possible to discriminate between sets of possible nucleon-nucleon phase shifts on the basis of nucleon-nucleus scattering and polarization.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**T9. Imaginary Part, $W$, of the Optical Model Potential for Neutron Interactions with Nuclei.** G. L. SHAW,* *Cornell University.*—The Brueckner nuclear many-body theory is modified so that it can be applied to the problem of dealing with quasi-stationary states. In this manner we are able to treat low-energy (several Mev) neutron interactions with heavy nuclei, taking into account the identity of the incident neutron with the nucleons in the nucleus. In calculating $W$, exact treatment of the pair interactions was made possible through the use of some $G$ matrix elements determined by Brueckner, Gammel, and Weitzner.[1] Higher order corrections are considered. The results indicate a surface absorption potential: $W$, for a given incident neutron energy, has a constant central region and reaches a peak $>$twice the central value in the surface region. An investigation is made of the next step after the compound state is formed. For heavy nuclei, compound nucleus formation dominates over compound elastic scattering. For light nuclei ($A=50$ or lower), there may be fluctuations of the cross section related to two-particle states.

* Now at Indiana University.
[1] Private communication from Brueckner, Gammel, and Weitzner.

**T10. Evaluation of the Relativistic Dispersion Relations for Photo-Pion Production.** R. BLANCENBECLER,* *Princeton University*, AND S. GARTENHAUS, *Purdue University.*—Using the well-known relation between the matrix elements for photo-pion production and pion-nucleon scattering, we have evaluated the corresponding dispersion relations by assuming the dominance of the (3,3) phase shift under all dispersion inte-

grals. The approach is to take the standard dispersion-theoretic integral equations and to solve them exactly by including the crossing as well as the recoil terms. A comparison with earlier work[1] is facilitated by expanding in inverse powers of the nucleon mass. The results so obtained agree with those in reference 1 near threshold. However, in the neighborhood of the resonance, some differences do occur and these will be discussed.

* National Science Foundation Postdoctoral Fellow.
[1] Chew, Goldberger, Low, and Nambu, Phys. Rev. 106, 1345 (1957).

**T11. Analytic Properties of Scattering Amplitudes in Perturbation Theory.*** S. MANDELSTAM, *University of California, Berkeley.*—The analytic properties of scattering amplitudes as functions of both the energy and momentum transfer are examined in perturbation theory. It is shown that, for processes not involving strange particles, the modification of the Nambu representation previously proposed by the author is valid in fourth order, and the spectral functions can easily be found. The sixth-order term also satisfies the representation. The fourth- and sixth-order terms can be generated from the lower order terms by using only unitarity and analyticity, and only the proved analyticity properties need be employed. If production is neglected in the unitarity condition,[1] the successively higher terms in the perturbation series can be generated from the lower terms using the unitarity and proved analyticity properties; the aforementioned representation is found to be true in all orders. The representation enables one to construct dispersion relations for individual angular-momentum states. The modifications in the representation necessary when there exist intermediate states with particles satisfying the mass inequalities of Karplus, Sommerfield, and Wichmann are discussed.

* Research supported by the U. S. Air Force.
[1] This limitation is probably unnecessary.

**T12. Puppi-Stanghellini Discrepancy.*** H. P. NOYES, *University of California, Livermore,* AND D. N. EDWARDS, *University of Liverpool, England.*—Although recently measured measured negative pion total cross sections at 40[1] and 96[2] Mev are in a direction to remove the discrepancy[3] between the pion-nucleon dispersion relations and experiment, Hamilton[4] cannot reconcile all existing data with these relations, while Salzman[5] finds the $f^2$ calculated from negative pion data between 100 and 200 Mev systematically (but not significantly) low. In order to decide what experiments would settle this question, it is necessary to calculate the error due to the integrals over the total cross sections, as well as that due to the scattering amplitudes and lengths. When this is done it is found that negligible error is introduced in calculations below 200 Mev by present uncertainties in the total cross sections above 350 Mev, but the better total cross section experiments are needed in the resonance region. Numerical results will be presented.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] S. W. Barnes *et al.*, Phys. Rev. (to be published).
[2] Holt, Edwards, and Frank, University of Liverpool (to be published).
[3] G. Puppi and A. Stanghellini, Nuovo cimento 5, 1305 (1957).
[4] J. Hamilton, Phys. Rev. 110, 1134 (1958).
[5] G. Salzman and J. H. Schnitzer (preprint).

**T13. Model for Pion Scattering and Photoproduction.*** RONALD F. PEIERLS, *Cornell University.*—An attempt is made to explain the various peaks observed in the cross sections for pion scattering and photoproduction at high energies in terms of the known $(\frac{3}{2},\frac{3}{2})$ resonance. The only additional assumption made is the existence of a strong, very short range, pion-pion interaction. It is shown, using only the laws of angular momentum and isospin, that the possibility of intermediate states of two pions should give rise to a peak in the photoproduction cross section in the $D_{\frac{3}{2}}$ state at about 700 Mev, and a corresponding peak for scattering. These should be almost entirely (95%) in the $T=\frac{1}{2}$ state. For scattering, but not for photoproduction there should be another peak, about 200 Mev higher, in an $F_{\frac{3}{2}}$ state, with isotopic spin branching ratio of 4:1 favoring $T=\frac{3}{2}$. Very tentatively one would expect peaks due to three pion intermediate states several hundred Mev higher, in the $T=\frac{3}{2}$ state. These predictions seem to fit quite well with the current data on the angular and energy dependence of photoproduction and scattering.

* Partially supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**T14. $i=\frac{1}{2}$ $\pi$-$N$ Resonances and the $\pi$-$\pi$ Interaction.** C. GOEBEL AND H. SCHNITZER,* *University of Rochester.*—The $\pi$-$\pi$ interaction is generally suspected to be important in the $\pi$-$N$ interaction above $\frac{1}{2}$ Bev. Photoproduction experiments seem to show that above the ${}_{\frac{3}{2}}P_{\frac{3}{2}}$ resonance the next resonance is ${}_{\frac{1}{2}}D_{\frac{3}{2}}$; this might in fact be due to a $\pi$-$\pi$ interaction of the simplest form, namely $\phi^4$. An important virtual process contributing to an effective $\pi$-$N$ ${}_{\frac{1}{2}}D_{\frac{3}{2}}$ potential is one suggested by R. Peierls: the $D_{\frac{3}{2}}$ meson collides with a $(P_{\frac{3}{2}})$ meson emitted by the nucleon; one of the resulting scattered mesons resonates with the nucleon in a ${}_{\frac{3}{2}}P_{\frac{3}{2}}$ state, the other in an $S$ wave; these mesons then scatter back to the original state. One expects that this process, but with the other meson in a $P$ wave, might cause resonances in other states at higher energy, i.e., the next should be $P_{\frac{1}{2}}$, $P_{\frac{3}{2}}$, and $F_{\frac{5}{2}}$. These resonances are all in the $i=\frac{1}{2}$ state because the effective potential resulting from the above described virtual process is five times stronger for $i=\frac{1}{2}$ than for $i=\frac{3}{2}$. Results of calculations made in the Chew-Low formalism following the above model shall be presented.

* Predoctoral National Science Foundation Fellow.
[1] See R. Peierls, Phys. Rev. Letters 1, 174 (1958).

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SATURDAY MORNING AT 10:05

Grand Ballroom

(J. W. BEAMS presiding)

## *Invited Papers in Nuclear Physics*

**TA1. Elastic Scattering of Completely Polarized 8- and 10-Mev Protons by Complex Nuclei.** LOUIS ROSEN, *Los Alamos Scientific Laboratory.* (30 min.)

**TA2. Nuclear Structure Models for the Lighter Nuclei.** E. B. PAUL, *Atomic Energy Research Establishment, Harwell.* (30 min.)

**TA3. Collective Motion in Certain Light Nuclei.** H. E. GOVE, *Chalk River Laboratories.* (30 min.)

**TA4. Study of Nuclear Energy Levels by Means of Inelastic Neutron Scattering.** JOAN FREEMAN, *MIT.* (30 min.)

SATURDAY MORNING AT 10:00

Panel Room

(ROBERT BERINGER presiding)

## *Heavy-Ion Bombardment*

**U1. Characteristics of Various Scintillation Crystals under Bombardment by Heavy Ions.*** E. NEWMAN, F. E. STEIGERT, AND L. C. NORTHCLIFFE, *Yale University*.—The pulse height *vs* incident energy has been measured for several heavy ion beams such as $He^4$, $C^{12}$, $N^{14}$, $O^{16}$ in thallium activated alkali halides and in organic crystals. The particles were accelerated to 10 Mev/nucleon in the Yale heavy ion accelerator, magnetically analyzed, scattered to reduce the intensity, degraded in energy by aluminum absorbers, reanalyzed and detected. Thin crystals ranging from 0.5 mm to 2 mm were used. Nuclear emulsions were exposed concurrently to provide internal checks on the identity of the beam, etc. It would appear as though the pulse height *vs* *E* follows a gentle "*S*" curve. The low-energy portion of the $N^{14}$ ions in CsI reproduces well the data of Halbert, and the over-all shape of the curves corresponds to the results of Burcham. Resolution is apparently going as the inverse square root of the energy with the exception of a few anomalous points at low energies where better than predicted resolutions are obtained. It was observed that exposure to a beam on the order of $10^7$ particles/sec affected the resolution adversely. Normalization for the response of a particular species of crystal to the various beams was made using the 8.78-Mev alpha of ThC′.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.

**U2. Range-Energy Relations of Heavy Ions in Nuclear Emulsion.*** P. G. ROLL AND F. E. STEIGERT, *Yale University*.—The range-energy relations for $He^4$, $C^{12}$, $N^{14}$, and $O^{16}$ ions in Ilford G-5 nuclear emulsions have been determined, using the Yale Heavy Ion Linear Accelerator. Both magnetic analysis and elastic scattering were employed to obtain known heavy ion energies in the range 0 to 10 Mev per nucleon. The resulting range-energy curves agree reasonably well with those calculated by Papineau,[1] although there is some evidence of a small systematic deviation. This agreement would substantiate the relation used by Papineau for the effective charge as a function of velocity. The ranges in other types of emulsion were found not to differ appreciably from those in G-5 emulsion. A characteristic of heavy ion tracks in the more sensitive emulsions is a unique taper region. The taper length for oxygen ions in G-5 emulsion, for example, has been established as corresponding to a residual range of $84_\mu$ (103 Mev).

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] A. Papineau, Comp. rend. 242, 2933 (1956).

**U3. Elastic Scattering of Oxygen Nuclei from Aluminum.*** J. A. MCINTYRE, S. D. BAKER, AND T. L. WATTS, *Yale University*.—Oxygen nuclei, accelerated to 160 Mev by the Yale Heavy Ion Linear Accelerator, have been elastically scattered from aluminum nuclei. The scattered oxygen nuclei have been detected at different scattering angles with a ¼ mm thick CsI scintillation crystal and photomultiplier. The differential cross section for the elastic scattering is found to drop rapidly below the Rutherford scattering cross-section for scattering angles greater than about 8° in the center-of-mass system. This result is to be contrasted to the diffraction structure obtained when 40-Mev alpha particles are scattered from aluminum[1] (40-Mev alpha particles have the same classical scattering properties as 160-Mev oxygen nuclei). Presumably, the shorter wavelengths of the oxygen nuclei or possibly distortions of the aluminum nuclei by the higher charge of the oxygen nuclei can be made to account for the disappearance of the diffraction structure when the bombarding particle is changed from the alpha particle to the oxygen nucleus.

* Work supported by the U. S. Atomic Energy Commission.

[1] Igo, Wegner, and Eisberg, Phys. Rev. 101, 1508 (1956).

**U4. Alpha Particles and Protons Emitted in High-Energy Heavy Ion Reactions.*** W. J. KNOX, A. R. QUINTON, AND C. E. ANDERSON, *Yale University*.—Alpha particles and protons emitted from nuclei bombarded by high-energy heavy ions have been observed. Particles are identified by measurement of $dE/dx$ with a proportional counter and total energy $E$ with a CsI crystal. Energy spectra are obtained by gating a multichannel analyzer from coincidences between $dE/dx$ and $E$ pulses within desired pulse-height limits. Alternatively energy spectra or ratios of numbers of alphas and protons emitted are determined from a photograph of an oscilloscope display of $dE/dx$ *vs* $E$ for individual particles. Energy spectra and relative numbers of alpha particles and protons emitted from Au and Ni targets bombarded with 70-Mev and 160-Mev oxygen nuclei have been measured. The energy spectra have broad maxima at approximately the energy indicated by barrier penetration. The high-energy tails of the spectra from Ni and the alpha to proton ratio increase at the higher bombarding energy. Further details of the reactions producing these particles are under investigation.

* Work supported by the U. S. Atomic Energy Commission.

**U5. Elastic Scattering of $N^{14}$ by $Be^9$.** M. L. HALBERT AND A. ZUCKER, *Oak Ridge National Laboratory*.*—The angular distribution of $N^{14}$ elastically scattered by $Be^9$ has been measured between 33° and 144° (c.m.) at intervals of about 4°, at a mean laboratory energy of 27.2 Mev. Two independently movable scintillation counters in a 24-in. scattering chamber were operated in coincidence, one detecting the scattered $N^{14}$ while the other detected the recoil $Be^9$. The pulse-height spectrum from one counter was displayed on a multichannel analyzer gated by pulses from the other counter. This scheme distinguished elastic scattering events from inelastic scattering, reaction products, and scattering from target impurities. From 33° to about 70° the cross section drops smoothly, and more rapidly than the Coulomb cross section. At larger angles structure is evident. Typical values of the ratio of observed to Coulomb scattering are: 33°, 0.46; 50°, 0.26; 70°, 0.12; 90°, 0.078; 110°, 0.039; 130°, 0.035. The absolute accuracy of these ratios is about 20%, due mostly to uncertainty in the target thickness. The relative accuracy is 5 to 10%.

* Operated for the U. S. Atomic Energy Commission by Union Carbide Corporation.

## *Post-Deadline Papers, If Any*

SATURDAY MORNING AT 9:30

Governor Clinton Hotel

(R. M. BOZORTH presiding)

## *Magnetism*

**UA1. Microprobe for Magnetic Field Mapping.** D. D. ROSHON, JR., B. KOSTYSHYN, AND R. L. LYON, *IBM, Endicott.*—The Hall effect has been widely applied to the measurement of magnetic fields. The relatively simple geometry of a Hall element suggests the use of such a device on a microscale as a probe for examining the fields of small structures. A Hall probe has been constructed which has a sensitive area smaller than 25×25 microns. Fields of less than 0.01 gauss have been measurable using evaporated bismuth films. Probe fabrication techniques will be described and the factors affecting probe performance will be discussed. A number of instrumentation systems, which have been proven suitable for measuring the small dc magnetic fields and high-frequency ac fields, will be described. High accuracy (1%) of field measurement is readily attained.

**UA2. Theoretical Determination of External Magnetic Fields in the Vicinity of Gap Structures.** E. E. FRANCIS AND C. M. BRUEN, *IBM, Endicott.*—Theoretical solutions have been achieved which describe the magnetic fields in the vicinity of gaps in ferromagnetic structures, such as a magnetic recording head. Two different structures have been treated. In one, the faces of the structure are perpendicular to the plane of the gap. The faces of the other structure form an acute angle with the plane of the gap. Potential, field vector, and horizontal and vertical field components are given as a function of the spatial coordinates.

**UA3. Geometric Dependence of Magnetic Anisotropy in Thin Iron Films.*** THOMAS G. KNORR† AND R. W. HOFFMAN, *Case Institute of Technology.*—Thin iron films produced by vacuum deposition are observed to display a magnetic anistropy dependent on the geometric location of the evaporating filament. A fiber axis structure is induced during the evaporation. If the direction of incidence of the metallic flux varies from a normal to the substrate this fiber axis tilts in a similar direction. As soon as the fiber axis is no longer normal to the plane of the film, magnetic anisotropy is produced. The variation of the tilt of the fiber axis in iron films correlates with and can be shown to account for the geometric dependence of the observed anisotropy, Calculations of the magnetic anisotropy expected in a film with a fiber axis structure and an anisotropic tensile stress in the plane of the film agree with the experimental observations for those films which show only rotational switching. Anisotropies of $3\times10^4$ ergs/cm$^3$ have been observed in iron films about 350 A thick prepared without the use of applied magnetic fields either during deposition or during a subsequent thermal anneal.

* Supported by the U. S. Atomic Energy Commission and the National Carbon Company.

† Now at the University of Dayton.

**UA4. Magnetic Structure Change in $Mn_{0.9}Li_{0.1}Se$. I. Neutron Diffraction Measurements.*** S. J. PICKART, *U. S. Naval Ordnance Laboratory and Brookhaven National Laboratory,* R. NATHANS, *Pennsylvania State University and Brookhaven National Laboratory,* AND G. SHIRANE, *Westinghouse Research Laboratory.*—Neutron diffraction measurements have revealed a ferromagnetic-antiferromagnetic phase change in $Mn_{0.9}Li_{0.1}Se$ at 70.5°K. This compound has the rock-salt structure (metal atoms face-centered); from the room temperature data the Li apparently replaces the Mn at random. At 77°K the neutron diffraction data are consistent with the ferromagnetic moment[1] of about 0.7 $\mu_B$ observed by magnetic measurements. At 4.2°K the spins have antiferromagnetic ordering of the third kind,[2] which results in tetragonal magnetic symmetry, the original unit cell being doubled in one direction. The observed intensities require the spins to lie at 45° to the unique axis. The measured temperature dependence of the principal superlattice reflection indicates the Néel temperature is near 70°K. This type of spin alignment has a nearest and next nearest neighbor environment considerably different from ordering of the second kind, found[3] in MnSe, and the change may be due to positive double-exchange bonds[4] introduced by the Li substitution.

* Performed in part at Brookhaven National Laboratory under the auspices of the U. S. Atomic Energy Commission and the National Science Foundation.

[1] R. R. Heikes and W. D. Johnston, Bull. Am. Phys. Soc. Ser. II, 2, 98 (1958).
[2] P. W. Anderson, Phys. Rev. 79, 705 (1950).
[3] Shull, Strauser, and Wollan, Phys. Rev. 83, 333 (1951).
[4] C. Zener, Phys. Rev. 82, 403 (1951).

**UA5. Magnetic Structure Change in $Mn_{0.9}Li_{0.1}Se$. II. Magnetic Measurements.** R. R. HEIKES, *Westinghouse Research Laboratories,* T. R. MCGUIRE, AND R. J. HAPPEL, JR., *U. S. Naval Ordnance Laboratory.*—The occurrence of ferromagnetism[1] at 77°K in $Mn_{0.9}Li_{0.1}Se$ has been further investigated in the region covered by the neutron diffraction measurements described in the preceding abstract. In the temperature range above 107°K the material is paramagnetic and the slope (above 300°K) of the reciprocal susceptibility with temperature indicates an average Bohr magneton ($\mu_B$) value of 4 spins per molecular unit, which is in agreement with the assumption of zero moment[2] for $Mn^{+++}$ and 5 $\mu_B$ for the remaining $Mn^{++}$. The ferromagnetic Curie temperature is 107°K and at 77°K the magnetic moment is 0.7 $\mu_B$. At 69°K the spontaneous magnetic moment decreases to almost zero. Below 69°K the susceptibility has the magnitude of a paramagnetic or antiferromagnetic material but with a large magnetic field dependence indicative of a ferromagnetic impurity. On warming from 65°K the specimen did not return to the ferromagnetic state until 77°K indicating a temperature hysteresis. The temperature hysteresis was time dependent in that the specimen did return to the ferromagnetic state at 69°K on warming slowly. The measured susceptibility at 2° and 4.2°K was the same, $275\times10^{-6}$ emu/g, as corrected for ferromagnetic impurity. These results will be discussed in terms of electrical conductivity and the double exchange coupling.

[1] R. R. Heikes and W. D. Johnston, Bull. Am. Phys. Soc. Ser. II, 2, 98 (1958).
[2] W. D. Johnston and R. R. Heikes, J. Am. Chem. Soc. 78, 3255 (1956).

**UA6. External Fields from Domain Walls of Cobalt Films.** B. KOSTYSHYN, J. E. BROPHY, I. OI, AND D. D. ROSHON, JR., *IBM, Endicott.*—By scanning the surface with a Hall probe, domain patterns on thin cobalt films have been mapped by measuring the fringing flux normal to the film surface. The samples studied displayed a uniaxial direction of easy magnetization and were of a thickness of approximately 2000 A. At the domain boundaries, peak fields ranged in intensity from less than 0.5 to 5.0 oersteds. The probe to film gap was 13 microns. The sensitive area of the probe was a square of bismuth 25 microns on a side. It was observed that along

specific boundaries reversal of flux direction occurs. The boundaries exhibiting low peak fields were generally parallel to the easy direction of magnetization whereas the boundaries exhibiting high fields were skewed relative to the easy direction of magnetization. Kerr effect and Hall probe patterns for the same domain configuration are shown to agree in detail.

**UA7. Ferromagnetic Domain Wall as a Pseudo-Relativistic Entity.** C. P. BEAN AND R. W. DEBLOIS, *General Electric Research Laboratory.*—In a normal, static 180° domain wall the magnetization is forced by magnetostatic fields to lie in the plane of the wall. In the approximation that this condition persists in the moving wall, the motion of the wall in an applied field is easily obtained. The motion is that of a relativistic entity with a limiting velocity, $V_s=\gamma(8\pi A)^{\frac{1}{2}}$. In this equation, $\gamma$ is the gyromagnetic factor and $A$ is the exchange stiffness parameter. For iron, this limiting velocity (spin velocity) is $1.2\times10^6$ cm/sec. In addition, the thickness of the domain wall undergoes a Lorentz contraction appropriate to the ratio of the wall velocity, $V$, to the spin velocity, $V_s$. Lastly, the total energy per unit area of the domain wall is given by $m_0V_s^2/(1-(V/V_s)^2)^{\frac{1}{2}}$ where $m_0$ is the inertial mass unit area of the domain wall described by Döring[1] and $m_0V_s^2$ is the customary static wall energy. We stress that this solution is not exact inasmuch as the magnetization does precess, to some degree, out of the plane of the wall. We shall indicate the limits of this approximation.

[1] W. Döring, Z. Naturforsch. **3a**, 373 (1948).

**UA8. Ferromagnetic Resonance at High Signal Powers.** E. SCHLÖMANN, *Raytheon Manufacturing Company.*—An extension of Suhl's theory is described. The stationary response of a ferromagnetic insulator to a large driving field is calculated for the case in which the saturation of the resonance proceeds through excitation of spin waves with the same frequency as the signal. The interaction between the homogeneous mode and suitable spin waves, arising from inhomogeneities such as randomness of distribution of metal ions over available sites or polycrystallinity, cannot be taken into account by means of viscous damping terms in the equations of motion. At large signal powers adjoint pairs of spin waves are subject to a time varying coupling produced by the large amplitude of the homogeneous mode, and are simultaneously subject to a small driving field arising from the inhomogeneity interaction. The response of each spin wave pair increases smoothly with increasing power and becomes very large as the threshold condition is approached. The theory predicts that in the presence of a strong inhomogeneity interaction, the susceptibility should depend linearly on the incident power in the range of fairly low powers and that the onset of saturation should be gradual. In the absence of inhomogeneity interaction, the nonlinear effects should set in at a well-defined threshold.

**UA9. Antiferromagnetic Ground State.** J. C. FISHER, *General Electric Research Laboratory.*—The ground-state wave function for an antiferromagnetic spin array, corresponding to the Hamiltonian $H=J\Sigma(\text{neighbors})S_i\cdot S_j$, has been approximated by a simple linear combination of those basis vectors that can be derived from the idealized Néel ground state by transferring a few spin deviations between neighboring spins. (The Néel ground state contains two equivalent sublattices of spins, with $S_z=+S$ for all spins on one, $S_z=-S$ for all spins on the other. Each spin has $Z$ nearest neighbors, all on the other sublattice.) The resulting wave function is very nearly an eigenfunction of $H$, the corresponding energy is $\lambda_0=-[1+(2ZS-1)^{-1}]JZNS^2/2$, and the fractional spin alignment is $\theta=1-ZS/(2ZS-1)^2$. The energy is very close to that given by the spin wave approximation, but the fractional spin alignment lies about halfway between the spin wave value and unity.

**UA10. Optical Properties of Nickel Oxide.*** R. NEWMAN AND R. CHRENKO, *General Electric Research Laboratory.*—The absorption spectrum of single crystal NiO has been measured in the 0.1 to 6 ev range and its reflectivity spectrum from 0.025 to 10 ev. The absorption spectrum shows a series of lines from 1 to 3.5 ev arising from internal transitions of the Ni ion. A continuous background absorption occurs in the range from 0.1 to 3.5 ev whose magnitude increases with impurity concentration. The absorption coefficient rises steeply above 3.5 ev and reaches a value of $\sim10^6$ cm$^{-1}$ at and above 4 ev. An absorption line at 0.24 ev[1] is found to be temperature sensitive in both intensity and frequency in the range above 300°K. Its behavior suggests that it arises from a transition to an excited spin state of the antiferromagnet. The reststrahlen spectrum was observed with the following parameters: high and low frequency dielectric constants 5.4 and 12 respectively; energies of longitudinal and transverse optical mode vibrations 0.076 and 0.044 ev respectively.

* This work supported in part by the U. S. Air Force (WADC).
[1] R. W. Johnson and D. C. Cronemeyer, Phys. Rev. **93**, 634 (1954).

**UA11. Optical Absorption of CoO and MnO above and below the Néel Temperature.*** G. W. PRATT, JR., *Lincoln Laboratory,* AND R. COELHO, *M.I.T.*—The optical transmission of single crystals of CoO and MnO has been studied both in the paramagnetic and antiferromagnetic phases. Spectra were taken from 2.5 $\mu$ to 0.4 $\mu$ and from 342°K to approximately 10°K. A number of broad lines were found in both materials. No experimentally significant shifts in positions of absorption peaks occurred in MnO going from the paramagnetic to antiferromagnetic state although as in CoO the absorption coefficients decreased with decreasing temperature. For CoO shifts towards shorter wavelengths were found on decreasing the temperature and new absorptions appeared below the Néel temperature. All observed absorptions can be explained in terms of crystal field theory from which values for Racah coefficients and crystalline field parameter were determined. No structure resulting from crystalline distortion was observed on passing through the antiferromagnetic transition. In CoO the transition to the $^4A_2$ level of the $Co^{++}$ first appears at approximately 0°C and becomes resolved into two lines at 78°K. This separation is attributed to the Zeeman effect produced by strong exchange fields in the antiferromagnetic state. The strength of the exchange field and magnetic moment of the $Co^{++}$ ground state may be estimated by studying the $^4A_2$ transition.

* The work reported here was performed in part at Lincoln Laboratory, a technical center operated by Massachusetts Institute of Technology with the joint support of the U. S. Army, Navy, and Air Force, under contract.

**UA12. Spin Structure of Antiferromagnetic $MnTiO_3$.*** G. SHIRANE, *Westinghouse Research Laboratories,* AND S. J. PICKART, *U. S. Naval Ordnance Laboratory and Brookhaven National Laboratory.*—$MnTiO_3$ has a rhombohedral crystal structure isomorphous with $FeTiO_3$, consisting of alternating layers of Mn and Ti atoms perpendicular to the rhombohedral axis with oxygen layers between them. A study of the magnetic properties of Mn $TiO_3$ by Ishikawa[1] revealed an antiferromagnetic Néel temperature at 30°K and suggested a spin structure different from that of $FeTiO_3$.[2] Powder neutron diffraction data taken at 4.2°K show that the magnetic structure consists of $Mn^{2+}$ spins arranged antiparallel within the same layer, in contrast to the case of $FeTiO_3$, where the $Fe^{2+}$ spins are parallel within the same layer and adjacent layers are antiparallel. The spin direction is along the rhombohedral axis, as is the case in $FeTiO_3$.

* Supported in part by the U. S. Atomic Energy Commission and the National Security Agency.
[1] Y. Ishikawa (to be published).
[2] Shirane, Pickart, Nathans, and Ishikawa (to be published).

**UA13. Antiferromagnetic Ground State.** J. C. FISHER, *General Electric Research Laboratory.*—The ground-state wave functions for an antiferromagnetic spin array, corresponding to the Hamiltonian $H=J\Sigma(\text{neighbors})\mathbf{S}_i\cdot\mathbf{S}_j$, has been approximated by a simple linear combination of those basis vectors that can be derived from the idealized Néel ground state by transferring a few spin deviations between neighboring spins. (The Néel ground state contains two equivalent sublattices of spins, with $S_z=+S$ for all spins on one, $S_z=-S$ for all spins on the other. Each spin has $Z$ nearest neighbors, all on the other sublattice.) The resulting wave function is very nearly an eigenfunction of $H$, the corresponding energy is $\lambda_0=-[1+(2ZS-1)^{-1}]JZNS^2/2$, and the fractional spin alignment is $\theta=1-ZS/(2ZS-1)^2$. The energy is very close to that given by the spin wave approximation, but the fractional spin alignment lies about halfway between the spin wave value and unity.

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SATURDAY MORNING AT 9:30

Terrace Room

(W. W. BUECHNER presiding)

## *Invited Paper*

**V1. Tandem Electrostatic Accelerators.** R. J. VAN DE GRAAFF, *M.I.T.* (30 min.)

## *Accelerators*

**V2. Stability Limits in Three-Sector Cyclotron Magnet.*** H. G. BLOSSER, *Michigan State University.*—Radial and vertical stability limits for proposed MSU 50-Mev cyclotron have been calculated using procedures of Welton and Gordon[1] with magnetic field determined from 3-sector model magnet. Comfortable stability limits were found even near machine center where the operating point is close to $\nu_r=3/3$ resonance. For protons maximum stable radial amplitudes are $\pm0.9''$ at 4 Mev, $\pm1.3''$ at 10 Mev, $\pm1.8''$ at 16 Mev, and $\pm2.2''$ at 22 Mev. For $C^{4+}$ ions corresponding amplitudes are $\pm0.7''$ at 8 Mev, $\pm1.0''$ at 16 Mev, $\pm1.4''$ at 24 Mev, and $\pm1.4''$ at 32 Mev. Calculation of trajectories with vertical amplitude of $1''$ (corresponding to $\pm1''$ dee aperture) with MURA I11 Tempered Five code[2] showed complete stability. Initial calculations have been made for resonant deflection system in which the field at deflection radius is perturbed to shift operating point onto the 3/3 resonance. For efficient deflection it has been found essential to shape field so that $\nu_r$ does not shift as $r$ amplitude builds up.

* Supported in part by U. S. Atomic Energy Commission.
[1] T. A. Welton and M. M. Gordon, Oak Ridge National Laboratory Rept. No. 2598 (unpublished).
[2] F. T. Cole, Midwestern Universities Research Assoc. Rept. No. 377 (unpublished).

**V3. Fixed-Frequency Cyclotron.*** G. PARZEN,† *Midwestern Universities Research Association.*—The properties of the particle motion in a fixed-frequency cyclotron have been investigated and the results previously found by others have been extended. Results have been found for the tune and the equilibrium orbit as a function of the particle energy and for the magnetic field required to give a fixed frequency of rotation. The approximations made are such that the results should be valid for large flutter and for large tunes ($\nu\simeq\frac{1}{2}N$). The results of the theory for the California[1] and Oak Ridge[2] cyclotron models will be presented and will be compared with the results of numerical calculations.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the University of Notre Dame.
[1] Kelly, Pyle, Thornton, Richardson, and Wright, Rev. Sci. Instr. 27, 492 (1956).
[2] Blosser, Worsham, Goodman, Livingston, Mann, Moseley, Trammel, and Welton, Rev. Sci. Instr. 29, 819 (1958).

**V4. Calculations of Orbit Properties near the Ion Source in a Constant Frequency Cyclotron.*** S. C. MILLER, JR., AND D. A. LIND, *University of Colorado.*—Digital computer studies have been made on the orbits of ions injected into a fixed-frequency cyclotron by a conventional ion source and puller electrode. The electrostatic field configurations were approximated by suitable functions to match the fields obtained in an electrolytic tank, and a uniform magnetic field was assumed. The calculations were carried through five turns for various starting conditions such as distance from median plane, injection phase angle, and initial vertical velocity. Details will be presented. The following important results were obtained. Particles leaving the ion source during a rising rf voltage are lost within a few turns. Orbit centers at the end of five turns are displaced parallel to the dee edge from 0 to 4 cm. Defining slits will be needed for accurate injection into the alternating gradient fields. Only a moderate phase bunching is observed. A semiempirical expression for the electrostatic focusing as a function of radius in the machine indicates that at the extraction radius electrostatic effects are a few percent of the A.G. magnetic effects.

* Supported by the U. S. Atomic Energy Commission.

**V5. Radial Straight Sections in Spiral Sector FFAG Accelerators.*** F. T. COLE† AND P. L. MORTON, *Midwestern Universities Research Association.*—It is desirable to introduce radial straight sections into spiral sector accelerators in order to accommodate accelerating cavities of reasonable design and magnet windings. Such straight sections make the accelerator nonscaling, i.e., in general the betatron oscillation frequencies vary with energy and resonances may be crossed. These effects have been investigated analytically in the linear approximation. The equations of motion are now functions not only of the accelerator parameters, but also of the geometry of the radial straight sections and of the equilibrium orbit radius. If the number of spirals per revolution is $N$ and the number of radial straight sections per revolution is $p$, then all harmonic numbers $n<\frac{1}{2}q$, where $q$ equals $p$ divided by the greatest commmon divisor of $p$ and $N$, do not contribute to the change of betatron oscillation frequencies with energy. Since

the contributions of a harmonic to the frequencies decrease as the harmonic number increases, it appears that the variation of betatron oscillation frequencies with energy can be kept within acceptable limits.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the State University of Iowa.

**V6. Magnetic Fields of FFAG Accelerators.*** EDWARD S. AKELEY, *Purdue University and Midwestern Universities Research Association.*—These magnetic fields are represented in spherical coordinates $(r,y,\phi)$ where $y=(\pi/2)-\theta$. Thus the scalar potential of a spiral ridge accelerator of $N$ sectors is represented by

$$V=-V_0\left(\frac{r}{r_1}\right)^{k+1} Im\left\{iL^{(0)}{}_{k+1}+\Sigma_n f_n\left(\frac{r}{r_1}\right)^{inK} L^{(nN)}{}_{k+1+inK}e^{-inN\phi}\right\},$$

where $r_1$, $k$, $f_n$, and $V_0$ are constants. $L^{(nN)}{}_{k+1+inK}$ is a Legendre odd function of $\sin y$. Corresponding expressions can be given for the radial sector accelerators. These expressions represent scaling fields. Certain types of nonscaling fields are introduced by cutting slots for windings in pole faces, or by introducing straight sections in spiral ridge machines. These nonscaling fields are also represented by spherical harmonics. These representations make it possible to obtain very simple analytic expressions that show how these nonscaling fields are propagated from the pole faces into the region of the orbits.

* Supported in part by the U. S. Atomic Energy Commission.

**V7. On the Instability of a Coasting Beam of Particles.*** C. E. NIELSEN AND A. M. SESSLER, *Ohio State University and Midwestern Universities Research Association.*—In order to obtain a very intense beam of circulating particles for the purpose of studying beam-beam interactions, it has been proposed[1] to "stack" many bunches of particles which have been accelerated to nearly the same energy. On the basis of the single particle theory of radio frequency acceleration the particles will, when not subject to an oscillator, spread so as to form a beam of uniform density in azimuth. It is observed by a simple physical argument, that for accelerators operating above the transition energy (the particle frequency decreases with increasing particle energy) a monoenergetic distribution is longitudinally unstable when particle-particle interactions are taken into consideration. The general situation, including energy spread in the beam, is studied with the linearized Boltzmann equation in which particle-particle forces are accurately represented by a term depending only on the density gradient. The resulting dispersion relation shows that for a given accelerator and coasting beam there is a critical beam energy spread such that for a larger spread the beam is longitudinally stable. Mura models and proposed accelerators are shown to satisfy the criterion for stability.

* Supported by the National Science Foundation, the U. S. Atomic Energy Commission, and CERN.
[1] D. W. Kerst *et al.*, Phys. Rev. **102**, 590 (1950).

**V8. Two-Stream Amplification Processes in Particle Accelerators.*** A. M. SESSLER, *Ohio State University,* AND K. R. SYMON, *Midwestern Universities Research Association.*—The possibility of two-stream amplification processes in particle accelerators has been pointed out by Buneman. The methods discussed in the previous abstract have been used to study longitudinal instabilities in two interpenetrating beams. The Boltzmann equation is linearized about two azimuthally uniform beams with a given initial energy spread. The force between particles is calculated relativistically in the limit of perturbation wavelength large compared to the vertical aperture, in which case it depends only on the particle density gradient. A general solution is obtained by Laplace transform in time and Fourier transform in space for arbitrary initial conditions, and a criterion for stability is obtained which is in the form of a dispersion relation. For operation below the transition energy there exists a criterion for stability which even for monoenergetic beams is easily satisfied by all contemplated Mura accelerators. For operation above the transition energy each beam (if sufficiently monoenergetic) is as in the previous abstract unstable, but the instability is now enhanced by the two beam interactions. It is found however, that there exists a critical energy spread such that if both beams have a larger energy spread there is no instability. The Mura intersecting beam model and proposed accelerator are shown to be stable.

* Research supported by the National Science Foundation and the U. S. Atomic Energy Commission.

**V9. Stability Analysis of the Electron Beam in a Budker-Type Accelerator.*** JOACHIM B. EHRMAN, *U. S. Naval Research Laboratory.*—A quasistationary solution (QS) of the Boltzmann equation for the electron beam in dePackh's proposal for a Budker-type accelerator has been obtained,[1] and its stability is now investigated. The Boltzmann equation is linearized in the perturbations. The perturbation quantities are Fourier analyzed in $\theta$ and $z$, and different Fourier components are not linked by the equation. A Laplace transformation from time to $s$ is carried out,[2] and, by the use of a suitable boundary condition on the distribution function in phase space, 4 one-dimensional coupled inhomogeneous Fredholm equations of the second kind are obtained for the Laplace transforms $(\rho,\rho v_r,\rho v_\theta,\rho v_z)$ of the perturbation charge-current density components. The solutions are analytic in $s$ except where the Fredholm determinant (FD) of the system vanishes. If the FD has no roots for $Re\, s>0$, and no multiple roots for $Re\, s=0$, $QS$ is stable. For $m=0$ (sausage instability), the $\rho v_\theta$ equation is not coupled to $(\rho,\rho v_r,\rho v_z)$, and there are two FD's to be investigated, of which the smaller one $(\rho v_\theta)$ corresponds to a "corkscrew" type of motion.

* N.R.L. Problem 72H02-21.
[1] J. B. Ehrman, Bull. Am. Phys. Soc. Ser. II, **3**, 257 (1958).
[2] L. D. Landau, J. Phys. (U.S.S.R.) **10**, 25 (1946); I. B. Bernstein, Phys. Rev. **109**, 10 (1958).

**V10. Ion Magnetron.*** JOHN M. WILCOX, JAMES D. GOW, AND LLOYD SMITH, *University of California, Berkeley.*—The ion magnetron consists of an (approximately) axial magnetic field of 5 kilogauss with mirror peaks at the ends, and an (approximately) radial electric field between the outer cylinder and a central rod electrode which is 10 kv positive. The tube is 4 feet long and 9 inches in diameter. The deuterium gas pressure is less than a micron, so that ion mean free paths are long compared with tube dimensions. Most of the tube voltage drop is in an electron-rich sheath which forms just outside the central anode. Ionization of neutral gas molecules in this sheath is an irreversible mechanism for injecting high-energy ions into the containment region. The central anode is free to oscillate as a pendulum. Forces to cause this are large compared with those expected from the tube current of 1 amp, which indicates the presence of large circulating currents. The neutron yield is of the order of $10^4$ per sec. If the central electrode is displaced off center by 1 in., the tube current remains the same but the neutron yield drops by an order of magnitude.

* Work done under the auspices of the U. S. Atomic Energy Commission.

SATURDAY MORNING AT 9:30

Boston Room

(C. S. WU presiding)

## *Beta Emitters*

**VA1. Half-Life of $B^{12}$ and of $Na^{24m}$.*** A. W. SCHARDT AND ALBERT GOODMAN, *Los Alamos Scientific Laboratory.*—Half-lives in the millisecond range are observed most easily if the sample is activated by a pulsed beam of an accelerator and the activity is then observed between beam pulses. The output of a beam pulser[1] was applied to the electrostatic deflector of the large Los Alamos Van de Graaff. The induced activity was detected with a gated[1] scintillation counter and recorded on a 100- channel pulse-height analyzer. The half-lives were measured with a 9-channel time-delay analyzer[1] which was calibrated to 0.3%. Enriched $B^{11}$ was activated with 2.0-Mev deuterons, the reaction being $B^{11}(d,p)B^{12}$. The activity was detected with a plastic phosphor and could be followed over 9 half-lives. A mean value of $20.25\pm0.40$ msec for the $B^{12}$ half-life was obtained from a least squares fit of the data. $Na^{23}$ was activated with 4.0-Mev deuterons. The 472-kev gamma rays from the $Na^{24m}$ decay were detected with a NaI(Tl) crystal. In order to minimize background, the photopeak was selected with a single-channel pulse-height analyzer and a value of $19.9\pm0.7$ msec was found for the half-life.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] James P. Glore, Los Alamos Scientific Laboratory, Report LAC-2152; available from the Office of Technical Service, U. S. Department of Commerce, Washington 25, D. C.

**VA2. Metastable States in $Br^{77}$, $Br^{79}$, and $Br^{81}$.*** ALBERT GOODMAN AND A. W. SCHARDT, *Los Alamos Scientific Laboratory.*—According to nuclear systematics, it is to be expected that the low-lying 9/2+ level, which gives rise to $M2$ and $E3$ isomerism in the odd arsenic and rubidium nuclides, occurs also in bromine and is responsible for some of the unassigned short-lived activities ascribed to bromine.[1,2] Using a proton energy below the $p,n$ threshold, the odd bromine isomers were produced by a $p,\gamma$ reaction on targets enriched in $Se^{76}$, $Se^{78}$, or $Se^{80}$. It was found that $Br^{77m}$ decays by $101\pm10$ kev gamma rays with a half-life of $4.2\pm0.2$ min. The transition is presumably $E3$ between the 9/2+ level and the 3/2− ground-state. $Br^{79m}$ apparently decays also by an analogous $E3$ transition, giving rise to $208\pm10$ kev gamma rays with a $4.8\pm0.2$ sec half-life. Using the beam-pulsing technique described in the previous paper, a metastable state was found in $Br^{81}$ at $550\pm20$ kev which decays by two conincident, unresolved gamma rays of energy equal to $275\pm10$ kev with a half-life of $36.7\pm1.5$ μsec. Tentative spins and transition assignments are 9/2+ ($M2$) 5/2− ($M1+E2$)3/2−. It appears likely that $Br^{79m}$ and $Br^{81m}$ are responsible for activities observed previously.[1,2]

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] G. Scharff-Goldhaber and M. McKeown, Phys. Rev. **95**, 613A (1954).
[2] S. H. Vegors, Jr., and R. B. Duffield, Bull. Am. Phys. Soc. Ser. II, 1, 206 (1956) and private communication.

**VA3. Beta Decays of $C^{15}$ and $N^{16}$.*** D. E. ALBURGER, D. H. WILKINSON, AND A. GALLMANN, *Brookhaven National Laboratory.*—An iron-free intermediate-image spectrometer has been used to measure the beta-ray spectra and the positron-electron internal pair conversion lines occurring in 2.4-sec $C^{15}$ and 7.4-sec $N^{16}$ decays. $C^{15}$ emits betas of end point energies $(9.82\pm0.04)$ Mev, to the ½-ground state of $N^{15}$, and $(4.51\pm0.03)$ Mev, having relative intensities of $(32\pm2)\%$ ($\log ft=6.0$) and 68% ($\log ft=4.1$), respectively. Both components have the allowed shape. From pair line measurements at 1.5% resolution the $C^{15}$ gamma-ray energy is $(5.299\pm0.006)$ Mev and thus the inner beta group leads to the upper member of the (5.276–5.305)-Mev doublet known from the $N^{14}(d,p)N^{15}$ reaction. The internal pair conversion coefficient of the 5.299-Mev line, derived by comparing with the known 6.14-Mev $E3$ line in $N^{16}$, agrees best with an $E1$ assignment. All of our data are consistent with spin ½+ for the 5.305-Mev level in $N^{15}$ and with spin ½+ for $C^{15}$. The 10.4-Mev ground-state beta in $N^{16}$ decay has the alpha forbidden shape and a relative intensity of $(26\pm2)\%$. Contrary to previous beta measurements the intensity of the 3.3-Mev component is found to be $<11\%$ per decay, based on the Kurie plot analysis. That the 3.3-Mev beta branch is 4.9%, as calculated from a previously measured (7.11/6.14)-Mev gamma intensity ratio of 1/14, is confirmed by the measured intensity of the 7.11-Mev pair line.

* Research carried out under contract with the U. S. Atomic Energy Commission.

**VA4. Angular Correlation Studies of Two Cascades in $Fe^{56}$.*** M. J. STIMAC, W. L. SKEEL, AND P. S. JASTRAM, *Ohio State University.*—Directional correlation measurements have been made on the 1.75−0.845 Mev and 2.10−0.845 Mev gamma-ray cascades in $Fe^{56}$ following the beta decay of 2.6 hr $Mn^{56}$. A fast-slow coincidence system was used to obtain a resolving time of approximately 20 mμsec. Differential pulse-height discriminators afforded selection of the 1.75- and 2.10-Mev lines, so that the two correlations could be measured separately.[1] The results for the 1.75−0.845 cascade are $A_2=0.2064\pm0.0043$ and $A_4=0.0088\pm0.0072$; for the 2.10−0.845 cascade, $A_2=0.06559\pm0.0062$ and $A_4=0.00875\pm0.0102$. The coefficients for the 1.75−0.845 cascade lead to a 2(1,2)2(2)0 spin and multipole assignment with a mixing ratio $\delta=0.06$ for the 1.75-Mev transition. The directional correlation coefficients for the 2.10−0.845 Mev cascade yield an equal choice between 3 and 2 for the spin of the 2.94-Mev level, with mixing ratios ($\delta$) of approximately −0.18 and −0.27, respectively. Spin 4 is in fact also a compatible assignment, but would require a small ($\delta=0.07$) admixture of octopole radiation.

* Supported by the U. S. Atomic Energy Commission.

[1] In the earlier work of Metzer and Todd, use of integral discriminators necessitated obtaining the 0.845–1.75 correlation by subtracting the 0.845–2.10 result from a composite correlation containing both high energy lines [Phys. Rev. **92**, 904 (1953)].

**VA5. Polarization-Direction Correlations in $Fe^{56}$.*** W. L. SKEEL, K. J. CASPER, AND P. S. JASTRAM, *Ohio State University.*—Polarization-direction correlation measurements have been made on the 1.75−0.845 Mev and 2.10−0.845 Mev cascades in $Fe^{56}$ following the decay of $Mn^{56}$. The directional correlation measurements described in the previous abstract yield an ambiguous assignment for the spin of the 2.94-Mev level, and give no information on the parity. Preliminary results confirm the spin assignment of 2 for the 2.60-Mev level, and show that the 1.75-Mev transition is a mixture of electric quadrupole and magnetic dipole radiation, so that the parity of the 2.60-Mev state is even. Results on the 2.10−0.845 cascade will be reported.

* Supported by the U. S. Atomic Energy Commission.

**VA6. Decay of $Zn^{63}$.*** J. B. CUMMING AND N. T. PORILE, *Brookhaven National Laboratory.*—The decay of 38.3-min $Zn^{63}$

has been investigated using scintillation and beta-spectrometer techniques. Zinc-63 decays predominantly by positron emission to the ground state of $Cu^{63}$. Gamma rays having energies of 0.67, 0.96, and 1.43 Mev are present with intensities of 10, 8, and 1.3 percent of the $\beta^+$ transitions. Low-intensity gamma rays (<0.2%) were observed with energies of 2.04, 2.34, 2.55, and 2.77 Mev as well as some indications of additional weak gammas of 1.5 and 1.8 Mev. The 0.67- and 0.96-Mev gamma rays are in coincidence with annihilation radiation but not with each other. An upper limit of 2% can be set for gamma rays having energies <0.67 Mev and in coincidence with positrons. Internal-conversion coefficients for the 0.67- and 0.96-Mev gamma rays were calculated from measured $\epsilon^-$, $\beta^+$, and $\gamma$-ray intensities. The results are in agreement with $M1$ assignments for both $\gamma$ rays. It is concluded that the 0.67- and 0.96-Mev $\gamma$ rays arise from transitions between known levels at these energies and the $Cu^{63}$ ground state.

* Research performed under the auspices of the U. S. Atomic Energy Commission.

**VA7. Nuclear Resonance Fluorescence in $Cu^{63}$*.** A. SUNYAR, J. B. CUMMING, L. GRODZINS, N. T. PORILE, AND A. SCHWARZSCHILD, *Brookhaven National Laboratory.*—Nuclear resonance fluorescence of the 670 kev and 960 kev $\gamma$ rays enitted in the decay of $Zn^{63}$ has been observed. A self-absorption measurement at room temperature yields a Doppler cross section of 8 barns/$Cu^{63}$ nucleus for the 670-kev line. This corresponds to a mean life of $(3\pm1.3)\times10^{-13}$ sec, if one assumes spin $\frac{1}{2}$ for the 670-kev state. The increase in the Doppler cross section of solid Cu at 77°K appears to be consistent with the theory of Lamb.[1] The 670-kev scattering yield is increased by a factor 4 upon dissolving a solid metal source in $HNO_3$. Using a liquid ($HNO_3$ solution) source, the ratio of 670 kev to 960-kev scattering yield from a $\frac{1}{2}$-in. Cu scatterer is $11\pm3$. This 960-kev scattering yield implies that $\tau_{960}<1.8\times10^{-13}(g_2/g_1)$ sec. Since collisions of the recoil from the preceding positron and $K$ capture will reduce the scattering yield, the actual lifetime is expected to be considerably shorter, in agreement with a previous measurement.[2]

* Work performed under the auspices of the U. S. Atomic Energy Commission
[1] W. E. Lamb, Jr., Phys. Rev. **55**, 190 (1939).
[2] K. Ilakovac, Proc. Phys. Soc. (London) **67A**, 601 (1954).

**VA8. Resonance Fluorescence from the 0.550-Mev Level of Selenium 76.*** JOHN R. PRUETT, *Bryn Mawr College.*—Using a gaseous source of arsenic 76 (arsine, $AsH_3$), the nuclear resonance fluorescence from the 0.550-Mev excited level of selenium 76 has been measured. Attempts to detect resonance fluorescence from the 1.2-Mev excited level of selenium 76 have so far been unsuccessful and a more careful investigation of this level is now in progress. The measured cross section $\bar{\sigma}$ is related to the mean life $\tau$ of the nuclear state by the formula $\tau=(g_2/g_1)(\lambda_0^2h/4\bar{\sigma})[N(E_{res})/N]$, where $E_{res}=E_0+(E_0^2/2MC^2)$ is the resonance energy in ev in the laboratory system, $N(E_{res})$ is the number of gamma rays per ev interval around $E_{res}$, and $M$ is the nuclear mass. If $N(E_{res})/N$ is computed for the $As^{76}$ decay on the basis of the latest proposed decay scheme and the naive assumption that one can neglect the beta-gamma and gamma-gamma angular correlations, one obtains a mean life for the 0.550-Mev level of $Se^{76}$ of $(2.6\pm0.3)\times10^{-11}$ sec. A more sophisticated calculation based upon the density matrix formulation for the first forbidden beta-gamma and beta-gamma-gamma angular correlations is in progress. This latter calculation has been carried out in order to analyze the 0.65 Mev gamma −0.55 Mev resonant-gamma-angular correlation which we have been attempting to measure. Some remarks may be made about this latter experiment.

* Research supported by the National Science Foundation.

**VA9. Charge Spectrometry for $Kr^{79}$-$Br^{79}$.** ARTHUR H. SNELL, F. PLEASONTON, AND J. L. NEED, *Oak Ridge National Laboratory.*—The charge spectrum associated with the complex decay scheme of $Kr^{79}$-$Br^{79}$ has been measured, and it has been found to decrease from charge −1 to an intensity minimum at charges +1 and +2, thereafter rising to a maximum at charge +4 and again decreasing to charge +13, where measurement stopped. The decrease from charge −1 to charges +1, +2 is attributable to recoils from the $\beta^+$ branches of the decay scheme, and this part of the spectrum is consistent in shape with that observed in the $\beta^-$ decay of $Kr^{85}$. The remainder of the spectrum is attributable to the $e$-capture branches. When corrections for the relative collection efficiencies are applied, as necessitated by the differences in recoil energies (6.5 ev max for $\beta^+$; 17.6 ev max for $e$ capture), the intensity ratio ($e$ capture)/$\beta^+$ can be brought into plausible agreement with the value $9.3\pm2$ found in beta spectrometry by Thulin *et al.*[1]

[1] Thulin, Moreau, and Atterling, Arkiv Fysik **8**, 229 (1954).

**VA10. Directional Correlation of the 690-kev Beta Group with 340-kev Gamma Ray in $Ag^{111}$.** J. H. HAMILTON,* B-G PETTERSSON, AND J. M. HOLLANDER,† *Institute of Physics, Uppsala.*—Recently it was pointed out that in cases where deviations from the "$\xi$ approximation" in once forbidden, nonunique transitions was observed in the shape factor additional information could be gained by measuring the deviations in other observables such as the $\beta$-$\gamma$ directional correlation.[1] A nonstatistical shape is reported[2] for the 690 kev $\beta$ group in $Ag^{111}$. The directional correlation of this group in coincidence with the 340-$\gamma$ ray was measured as a function of the $\beta$ energy. A magnetic lens spectrometer (10% momentum resolution) was used as the $\beta$ analyzer. Over 200 000 real coincidences were taken at five $\beta$ energies from 150 to 575 kev with a real/accidental$\geq5$ always. The correlation is nearly isotropic. The maximum anisotropy is $\lesssim-2\%$ at the highest energy measured. This result will be compared with theory.

* National Science Foundation Postcoctoral Fellow on leave from Vanderbilt University.
† On leave from University of California.
[1] T. Kotani and M. Ross, Phys. Rev. Letters **1**, 140 (1958).
[2] R. L. Robinson and L. M. Langer, Phys. Rev. (to be published).

**VA11. Conversion Electron Spectron of $Ce^{144}$.** J. S. GEIGER, R. L. GRAHAM, AND G. T. EWAN, *Chalk River Laboratories.*—The $\beta$-ray spectrum from $Ce^{144}$ has been studied at 0.1% momentum resolution with a 100-cm radius air cored $\pi\sqrt{2}$ $\beta$-ray spectrometer. More than forty conversion lines have been observed. Five arise from $K$-$2L$ Auger transitions and the remainder are assigned to $\gamma$ rays of 33.51 ($M1$), 40.88 ($M1$), 53.36 ($M1$), 58.96 ($M3$), 80.03 ($M1$), 99.85 ($E2$), and 133.42 kev ($M1$). The total relative transition intensities are estimated to be approximately 8, 8, 7, 8, 32, 1, and 100, respectively. The assigned multipolarities have been deduced from $K$, $L$ and $M$ subshell conversion line intensities and all appear to be pure. Levels with spin and parity assignments are proposed in $Pr^{144}$ at 0 kev (0−), $58.96\pm0.06$ kev (3−), $80.03\pm0.05$ kev (1−), $99.85\pm0.05$ kev (2−), and $133.42\pm0.05$ kev (1−). This level scheme is consistent with the energies, intensities and multipolarities of all the $\gamma$ transitions observed in these experiments.

**VA12. Decay of $Pr^{145}$.*** B. J. DROPESKY, D. C. HOFFMAN, AND W. R. DANIELS, *Los Alamos Scientific Laboratory.*—The radiations of 6-hr $Pr^{145}$ have been studied with a solenoidal $\beta$-ray spectrometer, scintillation spectrometers, and associated coincidence circuitry. Samples of $Pr^{145}$ were grown from its 3-min Ce parent which was rapidly separated from fission products resulting from short neutron irradiations of $U^{238}$. The Pr was specifically purified of Ce, Y, and Zr contamination with the final step being elution from a cation resin column.

The measured half-life of $Pr^{148}$ is 5.98±0.02 hr. The predominant (~95%) $\beta$ transition is to the ground state and has an endpoint energy of 1.805±0.010 Mev. The computed log ft value of 7.0 indicates that the transition is once forbidden. The remainder of the transitions are associated with $\gamma$ rays of energies: 0.072,[1] 0.68, 0.75, ~0.92, 0.98, 1.05, and 1.16 Mev. $\gamma$-$\gamma$ coincidence measurements showed that only the 0.68- and 0.98-Mev $\gamma$ rays are in coincidence with the 0.072-Mev $\gamma$ ray. Thus, excited levels of $Nd^{148}$ at 0.072, 0.75, ~0.92, 1.05, and 1.16 Mev appear to be populated by the $\beta$ decay of $Pr^{148}$. A tentative decay scheme, including transition intensities, will be presented.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Of the two levels of $Nd^{148}$ at 67 and 72 kev populated by the decay of $Pm^{148}$ reported by Brosi, Ketelle, Thomas, and Kerr (to be published), only *L*-conversion lines from the 72-kev transition were observed in the present study.

**VA13. Conversion Electron Spectrum of $Np^{239}$.** G. T. Ewan, J. S. Geiger, R. L. Graham, and D. R. MacKenzie, *Chalk River Laboratories.*—The conversion electron spectrum of $Np^{239}$ has been studied at 0.1% resolution with a 100-cm radius air-cored $\pi\sqrt{2}$ $\beta$-rays pectrometer. One hundred and twenty-seven lines were observed corresponding to Auger transitions or the internal conversion of $\gamma$ rays of energies 44.60, 49.35, 57.22, 61.43, 67.79, 88.00, 106.08, 106.42, 181.6, 209.7, 226.3, 228.1, 254.3, 272.7, 277.5, 285.4, 315.8, and 334.3 kev. The results require the addition of a level at 163.65 kev to the scheme proposed by Hollander *et al.*[1] in order to account for all observed gamma transitions. The $K=\frac{1}{2}$ ground-state rotational band in $Pu^{239}$ would then have members, 0 (1/2+), 7.87 (3/2+), 57.22 (5/2+), 75.66 (7/2+), 163.65 (9/2+). Using the values of the moment of inertia term $\hbar^2/2I=6.24$ kev and decoupling parameter $a=-0.58$, calculated from the levels at 7.87 and 57.22 kev the predicted positions of the 7/2+ and 9/2+ levels are 75.60 kev and 164.24 kev, respectively, in reasonable agreement with the experimental values.

[1] Hollander, Smith, and Mihelich, Phys. Rev. 102, 740 (1956).

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## Saturday Afternoon at 1:45

## Empire Room

## (J. Weneser presiding)

## *Theoretical Physics VI: Nuclear Theory, General Topics*

**W1. Triple Correlation Measurements Amenable to Simple Interpretation.** A. E. Litherland, *Chalk River Laboratories.*—The experimental results from triple correlations of the type $A(a,b,\gamma)B$ are usually very difficult to interpret because of the large number of parameters associated with the formation and decay of the compound nucleus. However, if the particles $b$ from the reaction are observed at 0° or 180° to the beam of particles $a$ and the resulting excited states have definite spin and parity, then the magnetic substates $m$ of the excited states of the residual nucleus $B$ that are populated are those with $|m| \leq S(A)+S(a)+S(b)$. $S(A)$, $S(a)$, and $S(b)$ are the spins of $A$, $a$, and $b$. The triple correlation expression in this case can be written in terms of the populations $P(m)$ of the magnetic substates, the gamma-ray multipolarities and the spins and parities of the states involved in the residual nucleus.[1] In the case of reactions such as $Mg^{24}(\alpha,p\gamma)Al^{27}$ only the $m=\pm\frac{1}{2}$ substates are populated. In this case the triple correlation coefficients are identical to the double correlation coefficients for the radiative capture of protons by even-even nuclei. Such double correlations have proved to be very useful in the determination of the properties of nuclear states.

[1] The same expression is used for the gamma ray correlations from an aligned nucleus. T. P. Gray and G. R. Satchler, Proc. Phys. Soc. (London) A68, 349 (1955).

**W2. Analysis of the Forbidden Reaction $B^{10}(d,p)^{11*}$ (2.14 Mev).*** F. S. Levin and W. M. MacDonald, *University of Maryland.*—This reaction is forbidden on the basis of angular momentum selection rules as applied to the usual Butler stripping amplitude. The exchange amplitude[1] arising from the use of properly antisymmetrized wave functions does not vanish, however.[2] In fact the exchange amplitude can be viewed as arising from the stripping of the target nucleus. In the calculation of this amplitude, therefore, the approximation of an infinitely heavy-target nucleus[2] is evidently unjustified, as already has been pointed out.[3] A calculation of the angular distribution now has been done taking into consideration the center of mass motion of the target nucleus. The results will be discussed.

* Investigation supported in part by the U. S. Atomic Energy Commission.

[1] G. E. Owen and L. Madansky, Phys. Rev. 105, 1766 (1956).
[2] A. P. French, Phys. Rev. 107, 1655 (1957).
[3] W. M. MacDonald, Bull. Am. Phys. Soc. Ser. II, 3, 170 (1958).

**W3. Angular Momentum of the Electron-Neutrino System in First Forbidden Beta Decay.*** C. E. Johnson, *University of California, Berkeley,* and R. W. King, *Purdue University.*—The nuclear shell model and the collective model are employed to predict the presence of sizable unique ($\Delta i=2$) components in particular classes of what are usually assumed to be non-unique first forbidden beta transitions ($\Delta I=0,\pm1$). The shell model argument depends only on the plausible assumption that configuration admixing is restricted primarily to configurations in the same *major* shell. The collective model argument depends only on the validity of the $K$-quantum number. Experimental evidence is surveyed to support each of these effects imposed on beta decay by the structure of the nucleus. It is proposed that first forbidden beta decay be used to explore the degree of configuration mixing in the shell model and the validity of the $K$-quantum number in the collective region. The analysis of several kinds of experiments will be strongly affected by the presence of the usually neglected unique components (e.g., experiments with oriented nuclei, $\beta$-$\gamma$ angular correlation experiments, etc.).

* Work supported by the U. S. Atomic Energy Commission and U. S. Air Force Office of Scientific Research.

**W4. Nuclear Force Parameters in the 1s Shell.*** Paul Goldhammer, *University of Nebraska.*—The second-order perturbation procedure of Bolsterli and Feenberg[1] has been employed to determine a two-body interaction operator that fits the experimentally known properties of nuclei in the first $s$ shell. The potential is of the Serber type, with Gaussian radial dependence. A short range Gaussian function furnishes the repulsive core, while the tensor component has a radial

dependence of the form $(r_{12}^2/r_0^2)\exp(-r_{12}^2/r_0^2)$. The binding energies of $H^2$, $H^3$, and $He^4$, the rms radii[2] of $H^2$ and $He^4$, the coulomb energy difference in $H^3$-$He^3$, and the quadrupole moment of $H^2$ are all fit to within 2% of the experimental values. The %$D$-state admixture in $H^2$ is found to be 7%, possibly representing the poorest aspect of the fit. No corrections were made for the finite extension of the nucleon.

* Supported in part by a grant from the University of Nebraska Research Council.
[1] M. Bolsterli and E. Feenberg, Phys. Rev. **101**, 1349 (1956).
[2] R. Hofstadter, Ann. Rev. Nuclear Sci. **7**, 231 (1957).

**W5. Doublet Splittings in Strongly Correlated Nuclei.*** J. SAWICKI AND R. FOLK, *Princeton University*.—The nucleon-nucleus LS coupling is calculated using the Brueckner type of theory and the strongly correlated nuclear core density obtained from Jastrow's theory applied to the finite nucleus. The two-body potentials are replaced by the two-body scattering operators calculated from the potentials of Gammel and Thaler and of Signell and Marshak. It was possible to avoid many approximations often made in calculations of this type and thus some important corrections to the leading Thomas-like term are included. The general theory is applied to the $O^{17}$ problem with Dabrowski variational trial functions of $O^{16}$ to calculate the core density. Both the correct sign and the correct order of magnitude of the doublet splitting of $O^{17}$ are obtained for both two-body potentials, and so this theory provides no clear distinction between these potentials.

* Supported in part by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

**W6. Electron Scattering from $N^{14}$.*** M. K. PAL, *University of Maryland* (introduced by R. Ferrell).—The elastic electron scattering data[1] for 420-Mev electrons have been analyzed with the first order Born approximation method. The ground state wave function of $N^{14}$ has been taken to be the intermediate coupling wave function suggested by Visscher and Ferrell[2] with an admixture of the spheroidal type of collective wave function developed by Fallieros and Ferrell.[3] Omitting the collective part from the wave function leads to a value of the differential cross section at the diffraction minimum which is only one-third of the observed value. Including the collective part in the wave function gives a good fit to the data at all angles except for a small region near the minimum where the predicted values are still about 20–30% lower. Attempts are being made to explain this discrepancy in terms of (1) spin-flip type scattering and (2) higher order Born approximation.

* Work supported in part by the U. S. Atomic Energy Commission.
[1] U. Meyer-Berkhout (private communication).
[2] W. M. Visscher and R. A. Ferrell, Phys. Rev. **107**, 781 (1957).
[3] S. Fallieros and R. A. Ferrell (to be published).

**W7. Application of the Quasi-α Model to Beta Decay and Nuclear Magnetic Moments.*** D. W. DORN AND R. W. KING, *Purdue University*.—The quasi-$\alpha$ model in $j$-$j$ coupling previously presented[1] has been applied to the calculation of beta-decay matrix elements and magnetic moments in the nuclear $d_{5/2}$ and $f_{7/2}$ shells. The model (in the $j$-$j$ coupling limit) need only be imposed to obtain *non-unique* wave functions, i.e., those wave functions for which the requirements that the total-angular momentum I and the isotopic spin $T$ be good quantum numbers are insufficient to determine the angular parts of the wave function. Twenty-three beta transition probabilities for which experimental comparison is possible have been calculated. The degree of agreement is just that found for the cases where only unique wave functions are required. This agreement is far superior to that obtained when the criterion of of seniority is imposed. The symmetry properties of the quasi-$\alpha$ structure are also more in accord with our knowledge of the nucleon-nucleon interaction than those implied by making seniority a good quantum number. In ten cases we have compared our calculated magnetic moments with experiment. While the agreement is good, we can claim no great improvement over other models, since magnetic moments appear rather insensitive to the choice of model.

* Supported in part by the Air Force Office of Scientific Research.
[1] R. W. King and D. W. Dorn, Bull. Am. Phys. Soc. Ser. II, **2**, 26 (1957).

**W8. Energy Level Structure of $Bi^{210}$ and $Po^{210}$.*** NEAL D. NEWBY, JR., *Indiana University*.—Calculations of the low-lying energy level structure of $Bi^{210}$ and $Po^{210}$ have been carried out based on a shell model picture of these nuclei. The single particle states available to the extra-core nucleons are found from the experimental data on $Pb^{209}$ and $Bi^{209}$. From these single particle states $jj$ coupled two-particle states are constructed. An interaction is "turned on" between the extra-core nucleons of the form $V(r)=J(r)[\pi_t+p\pi_s]\frac{1}{2}[1+P_M]$ where $\pi_t$ and $\pi_s$ are the triplet and singlet projection operators, respectively, $P_M$ is the Majorana operator, and $p$, the singlet to triplet well-depth ratio is 0.765. $J(r)=v_0\cdot\exp(-\beta r^2)$ with $v_0=60$ Mev and $\beta^{-\frac{1}{2}}=1.6$f. The energy eigenvalues and eigenfunctions are determined by diagonalizing in the space spanned by the zero-order $jj$ coupled states. The agreement with the experimental levels is good in $Po^{210}$. In $Bi^{210}$ the agreement obtained with a zero-range force is lost in going to a finite range interaction. Tensor force effects have been investigated in this case.

* Supported in part by the National Science Foundation.

**W9. RaE and the Shell Model.*** A. BINCER, E. CHURCH,† AND J. WENESER, *University of California, Berkeley*, and *Brookhaven National Laboratory*.—In an extension of previous work, an attempt has been made to correlate the spectral shape, longitudinal polarization, and lifetime of the beta decay of RaE($Bi^{210}$) in terms of the $jj$ coupling model with configuration mixing. The configurations considered important in the initial $(1-)$ state are: $(h_{9/2})_p^1(g_{9/2})_n^1$, $(h_{9/2})_p^1(g_{7/2})_n^1$, $(h_{9/2})_p^1(i_{11/2})_n^1$, and $(h_{11/2})_p^{-1}(h_{9/2})_p^2(g_{9/2})_n^1$. The final $(0+)$ state is taken as $(h_{9/2})_p^2$ plus the doubly magic $Pb^{208}$ core. Other admixed configurations would not contribute importantly to the beta-decay matrix elements. The immediate objective is the use of the experimental data to fix the mixture of configurations, with the usual assumptions of a two-component neutrino theory with $VA$ interactions invariant under time reversal. It has been found that the choices of nuclear configurations which best fit the shape and lifetime yield a longitudinal polarization of $\sim-(85$–$90\%)$ v/c.

* Guest scientist from Frankford Arsenal, Philadelphia, Pennsylvania.
† Work performed in part under the auspices of the U. S. Atomic Energy Commission and the U. S. Air Force Office of Scientific Research.

**W10. Field Theoretic Method of Correcting the Nuclear Shell Model for Correlation.*** RICHARD A. FERRELL, *University of Maryland*.—Single-nucleon excitation of a nucleus can be represented by a Feynman diagram consisting of two lines. The nucleon-nucleon interaction causes the annihilation of the pair and simultaneously the creation of a new particle-hole pair. The history of the eigenstate of the total Hamiltonian is thus a chain of bubbles. Both "forward-going" and "backward-going" bubbles occur, depending on whether the excitation is received before or after it is transmitted. Normalization is by an indefinite metric,[1] in which the squares of the forward *minus* the squares of the backward amplitudes sum to unity. Standard shell-model calculations err in omitting the backward amplitudes. Only by including them can correlation in the ground state be allowed for and the various sum rules[2] be satisfied. Example: 6.14-Mev $3-0^{16}$ excitation, whose experimental lifetime[3] is one-tenth that predicted by the uncorrected shell model.

* Investigation supported in part by the U. S. Atomic Energy Commission and by the Office of Naval Research.
[1] This normalization is already familiar in the theory of the electron plasma. See, for example, R. A. Ferrell, Phys. Rev. **107**, 450 (1957), Eq. (32); and R. A. Ferrell and J. J. Quinn, Phys. Rev. **108**, 570 (1957), Sec. IV.
[2] R. A. Ferrell, Phys. Rev. **107**, 1631 (1957), and references 3 and 4 therin.
[3] D. Kohler and H. H. Hilton, Phys. Rev. **110**, 1094 (1958).

**W11. Spheroidal Oscillation in $O^{16}$.*** S. FALLIEROS, *University of Maryland.*—A particular state of collective spheroidal oscillation in $O^{16}$ (quantum numbers $J=2+, T=0$) can be constructed by a coherent superposition of single particle excitations of the type $1s\rightarrow 1d$, $1p\rightarrow 2p$, and $1p\rightarrow 1f$. The approximate relative participations are, respectively, 17%, 13%, and 70%. This state can alternatively result from the application of a simple deformational operation on the ground state.[1] The total energy of excitation and the matrix element for the transition to the ground state have been calculated. The oscillator strength for this transition is seen to account for almost 90% of the limit of the electric quadruploe sum rule for $T=0$ states. Through nuclear interactions of the $O^{16}$ core with additional particles or holes this state can appear as an intermediate state in various electromagnetic transitions causing an appreciable enhancement to the single particle transition rates.

* Supported in part by the U. S. Atomic Energy Commission.
[1] R. A. Ferrell and W. M. Visscher, Phys. Rev. 102, 450 (1956) and 104, 475 (1956).

**W12. Physics Demonology.** JEROME ROTHSTEIN, *Edgerton, Germeshausen, and Grier, Inc.*—As all physical laws are constraints excluding behavior or relationships incompatible with them, they can be formulated as laws of impotence. Demons are then definable as hypothetical agents potent to violate particular laws; any law can be formulated as nonexistence of some demon. Of the infinity of possible demons three are of particular interest because they were invented, not *ad hoc*, but before their corresponding laws were well understood; they correspond to the laws of thermodynamics. Aladdin's demon, who could create matter and energy from nothing, is killed by the first law. Maxwell's demon, who acquired physical information (results of measurement) without paying an equivalent entropy increase, is destroyed by the second law. Laplace's demon (either the original or a quantum version), who, knowing the state of the universe at any one time knows all of the past and future, receives his coup de grâce from the third law (unattainability of absolute zero temperature). Demons born in pre-scientific times seem to be hybrids or special cases of those cited. It is worth emphasizing that unless a definite entropy equivalent for an item of physical information is admitted, Maxwell's and Laplace's demons would not be excluded.

**W13. A Retarded Reciprocal Potential Energy.** F. W. WARBURTON, *University of Redlands.*—The method of obtaining a reciprocal force, by means of a generalized gradient of potential energy of two electrical charges, is extended to include the time of propagation. The time derivative at the instant of emission is expressed in terms of the time derivative at the instant of reception; while the time of propagation is reckoned for ballistic emission with arrival at the receiver at speed $c+v_r'$. Evaluation of the coefficients in the power series formula specifies the retarded term in the potential energy. The result parallels the classical description in providing the transverse radiation electric field.

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## SATURDAY AFTERNOON AT 1:45

## Grand Ballroom

## (RICHARD WILSON presiding)

### *Scattering and Polarization of Electrons and Nucleons*

**WA1. Measurement of the Mott Asymmetry in Double Scattering of Electrons.*** D. F. NELSON AND R. W. PIDD, *University of Michigan.*—The Mott asymmetry was observed at 121 kev for gold targets and scattering angles of $\theta_1=90°$ and $\theta_2=80°$ to 140°. The cosine dependence of the asymmetry on the azimuthal angle was shown in all cases. A weak magnetic lens (maximum field: 12.5 gauss) was used between the two scatterers and a low resolution (8%) electrostatic energy analyzer was used after second scattering. The measured asymmetry amplitudes are compared with the calculations of Sherman (pure Coulomb field) and of Mohr and Tassie (screened Coulomb field). The experimental values for $\theta_2=90°$, 100°, 110° agree well with either theoretical curve but are not accurate enough to distinguish between them. The measured value at $\theta_2=80°$ is enough higher (17%) than the pure Coulomb field curve to indicate a screening effect. The experimental values for $\theta_2=120°$, 130°, and 140° fall from 15% to 20% below the theoretical curves. This discrepancy is attributed to plural scattering.

* This work was supported by the U. S. Atomic Energy Commission, Contract No. AT(11-1)-70.

**WA2. On the Determination of Electron Polarization by Means of Mott Scattering.** NOAH SHERMAN AND D. F. NELSON, *University of Michigan.*—Results of numerical calculation of the polarization asymmetry factor, $S(\theta)=\delta^1$, and the single-scattering cross section for scattering of electrons by point nuclei are presented. These calculations were performed on the UNIVAC but not reported with previously published data.[1] The present data apply to the scattering of electrons of 75 and 121 kev by gold, $Z=79$ and aluminum, $Z=13$, at angles between 15 and 165 degrees. These results, which ignore the effect of screening by atomic electrons, are compared with calculations of Mohr and Tassie,[2] who tried to estimate the effect of screening on Mott scattering by gold at 121 kev. The comparison between these results (indicating about 50% greater asymmetry for the screened field at angles near 165 degrees) suggests the desirability of more detailed investigations of screening effects in order to be confident of Mott scattering as a means of measuring the polarization of electrons. Numerical study of the screened field is being undertaken.

[1] N. Sherman, Phys. Rev. 103, 1601 (1956).
[2] C. B. O. Mohr and L. J. Tassie, Proc. Phys. Soc. (London) 67, 711 (1954).

**WA3. Energy Distribution of Inelastically Scattered Electrons.*** D. RAMPOLLA,† B. WALDMAN, AND W. C. MILLER, *University of Notre Dame.*—1.6 Mev electrons have been scattered from thin (0.8 to 2.4 mg/cm²) foils of aluminum, nickel, and gold. Electrons scattered inelastically through 120° with energies down to 45 kev were analyzed with a 90° magnetic spectrometer and detected by a plastic scintillator. The scintillator efficiency for low-energy electrons was measured by comparing the counting rate to the charge measured by a vibrating reed electrometer and found to be greater than 80% for all energies above 45 kev. The cross section below 300 kev increases rapidly with decreasing energy,

but the rate of increase and the values of the cross section differ markedly from the theory of Ford and Mullin,[1] which predicts much smaller cross sections at higher energies and a much more rapid rate of increase. Above 600 kev the results are an order-of-magnitude greater than the Parzen[2] theory.

* Supported in part by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
† Now at Westinghouse Atomic Power Division, Pittsburgh, Pennsylvania.
[1] G. W. Ford and C. J. Mullin, Phys. Rev., **110**, 520 (1958).
[2] McCormick, Kieffer, and Parzen, Phys. Rev. **103**, 29 (1956).

**WA4. Diffusion of Thermal Electrons in Atomic Oxygen from Shock Wave Studies.*** S. C. Lin, *AVCO Research Laboratory*.—The momentum transfer cross section of slow electrons in atomic oxygen has been deduced from simultaneous measurements of the dc electrical conductivity and the microwave absorption coefficient of a predominantly atomic oxygen gas mixture in a shock tube. The Maxwell-averaged cross section attributable to atomic oxygen was found to be about $1.5\times10^{-16}$ cm$^2$ at an electron temperature of 4000°K (mean thermal energy ~0.5 ev), indicating the existence of an antiresonance point for *S*-wave scattering by atomic oxygen at these low electron energies. While this value seems to be considerably smaller than all theoretical predictions,[1-3] it is not incompatible with the earlier conductivity measurement of high temperature air by Lamb and Lin[4] in view of the relative abundance of $N_2$ and N in the air mixture, and the limited accuracy within which their respective cross sections are known.

* Work supported by the Ballistic Missile Division of the U. S. Air Force.
[1] Hammerling, Shine, and Kivel, J. Appl. Phys. **28**, 760 (1957).
[2] Aaron Temkin, Phys. Rev. **107**, 1004 (1957).
[3] M. M. Klein and K. A. Brueckner, Phys. Rev. **111**, 1115 (1958).
[4] L. Lamb and S. C. Lin, J. Appl. Phys. **28**, 754 (1957).

**WA5. Slow Electron Scattering by Atomic Oxygen.*** B. Kivel and P. Hammerling, *AVCO Research Laboratory*.—Klein and Brueckner[1] have related the $O^-$ photoabsorption cross section measured by Branscomb *et al.*[2] to the low-energy electron scattering cross section of oxygen. In this way Klein and Brueckner demonstrated the inconsistency of the cross section favored by Hammerling, Shine, and Kivel to fit electrical conductivity measurements of air from 4000 to 6000°K by Lamb and Lin. Recently Lin[3] has made a more definitive measurement of oxygen alone and finds the value $1.5\times10^{-16}$ cm$^2$ which is considerably smaller than $10\times10^{-16}$ cm$^2$ suggested by Klein and Brueckner. The latter value should be reduced since the $O^-$ process gives information only about the doublet state which accounts for only one-third of the scattering events. The quartet state electrons, which are subject to a stronger exchange force, will have a smaller cross section. If the quartet electrons make a negligible contribution to the scattering, then the remaining difference between theory and experiment can be attributed to minor uncertainties.

* Work supported by BMD ARDC.
[1] M. M. Klein and K. A. Brueckner, Phys. Rev. **111**, 1115 (1958).
[2] Branscomb, Burch, Smith, and Geltman, Phys. Rev. **111**, 504 (1958).
[3] S. C. Lin, preceding paper.

**WA6. Absolute Elastic Electron-Scattering Cross Sections of Ca, V, Co, In, Sb, and Bi at 183 Mev.*** M. R. Yearian, J. Oeser, and R. H. Helm, *Stanford University*.—The detector ladder described by Kendall[1] has been used in measuring the elastic electron-scattering cross sections of Ca, V, Co, In, Sb, and Bi, at several angles at 183 Mev. Absolute cross sections are obtained by comparison with the scattering from hydrogen. The earlier work of Hahn, *et al.*[2] on the same elements yielded angular distributions which were analyzed by Ravenhall, using a Fermi two-parameter model, in terms of $c$ (radius to half-maximum), $t$ (90% to 100% surface thickness), and the cross section $\sigma(\theta)$. Ford[3] has analyzed these data using a very similar charge distribution and finds that in general there is an alternate solution characterized by values of $c$ and $t$ quite close to Ravenhall's best values, and by cross sections which vary from 0.6 to 0.85 of Ravenhall's values. Preliminary examination of the present work indicates that measured absolute cross sections are more nearly in agreement with those predicted by the original analysis[2] than with those predicted by Ford's alternate solutions.

* Supported by the joint program of the Office of Naval Research, U. S. Atomic Energy Commission, and Air Force Office of Scientific Research.
[1] H. W. Kendall (to be published).
[2] Hahn, Ravenhall, and Hofstadter, Phys. Rev. **101**, 1131 (1956).
[3] K. W. Ford and D. L. Hill, Ann. Rev. Nuclear Sci. **5**, 25 (1955).

**WA7. *P-P* Triple Scattering at 145 Mev.*** C. F. Hwang,† T. R. Ophel, N. F. Ramsey,‡ E. H. Thorndike, and Richard Wilson, *Harvard University*.—The depolarization parameter $D$ has been measured for angles less than 45° lab. Our results show $D$ to decrease smoothly from 0.15 at 20° to zero at 35° with statistical errors varying from ±0.04 at 20° to 0.12 at 35°. At the larger angles (30° to 35°) our results differ drastically from those of A. E. Taylor who reported a value of $D=-0.57\pm0.16$ for 35°.[1] Possible reasons for this discrepancy will be discussed. In general, Taylor's results seem to substantiate the Signell-Marshak[2] phase-shift calculation whereas our results tend to agree with the Gammel-Thaler prediction.[3]

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Holder of Corning Glass Works Foundation Predoctoral Fellowship.
‡ Now at NATO, Paris.
[1] 1958 Annual International Conference on High Energy Physics at CERN, p. 56.
[2] P. S. Signell and R. E. Marshak, Phys. Rev. **109**, 1229 (1958).
[3] J. L. Gammel and R. M. Thaler, Phys. Rev. **107**, 291 (1957).

**WA8. Inelastic *p,d* Scattering.*** A. F. Kuckes and Richard Wilson, *Harvard University*.—The 145-Mev, 70% polarized proton beam of the Harvard Cyclotron has been used to measure the quasi-elastic $p,p$ cross section and polarization of deuterium in the angular range from 25° to 65° lab. The kinematics of each event are determined by measuring the energy and direction of one proton and the direction of the recoil proton. The energy dependence of the scattered particles and also the "included" angle dependence of the cross section is found to behave in qualitative agreement with what one would expect from impulse approximation notions. Measurements are in progress to measure quastic $p,n$ polarization in this same angular range.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**WA9. Elastic Scattering of 146 Mev Polarized Protons by Deuterons.*** Herman Postma and Richard Wilson, *Harvard Cyclotron Laboratory*.—The absolute differential cross section and polarization of 146 Mev protons scattered by deuterons have been measured in the center-of-mass angular range 3.75° to 170°. Apparatus with an energy resolution of 2.2% detected protons scattered by a liquid deuterium target at small and intermediate angles (3.75° to 110°) and detected their elastically recoiled deuteron partners at larger angles (100° to 170°). The polarization rises quickly to a maximum of 60% at 35°, goes to 0 at 61° and to a minimum of −60% at 100°, rising once more to 0 at 135° to a maximum of 18% at 155° and then toward 0 at 180°. The cross section displays a Coulomb interference minimum at 10° and then falls to a minimum of 0.2 mb/sterad at 120° later exhibiting the usual rise due to deuteron pickup at the larger angles. Both polarization and cross section are well fitted by the Signell-Marshak and Gammel-Thaler potential predictions at the small angles (<70°); failure at larger angles being due to multiple scattering and off energy shell scattering.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

**WA10. Polarization of Neutrons from the Reactions $Li^7(p,n)Be^7$ and $D(d,n)He^3$.** J. A. BAICKER, K. W. JONES,* AND B. TELL,† *Columbia University.*—The degree of polarization of neutrons has been measured for the $Li^7(p,n)Be^7$ reaction at a laboratory angle of 50° for proton energies from 3.0 to 6.0 Mev, and for the $D(d,n)He^3$ reaction at a laboratory angle of 40° for deuteron energies from 2.0 to 4.5 Mev. Liquid helium contained in a thin-walled Dewar was used as a polarization analyzer. A millimicrosecond time-of-flight system was used for neutron detection. For the $Li^7(p,n)Be^7$ reaction the polarization is approximately $+0.35$ in the proton energy region from 3.0 to 4.0 Mev, and at $E_p=5.8$ Mev it is $-0.30$. The polarization is zero at $E_p=5.1$ Mev. Below 4 Mev only neutrons going to the ground state of $Be^7$ were counted, but for higher proton energies the measured polarization is the net value of the ground and first excited states combined. The (negative) polarization in the $D(d,n)He^3$ reaction has a maximum value of 0.21 at around $E_d=2.0$ Mev, decreasing slowly to approximately 0.15 at $E_d=4.5$ Mev.

* Now at The Ohio State University.
† Now at the University of Michigan.

**WA11. Polarization of Protons Elastically Scattered in Deuterium.*** S. M. SHAFROTH, R. E. SEGEL,† R. CHALMERS, AND E. N. STRAIT, *Northwestern University.*—The polarization of 3.3 Mev protons has been measured for 90° c.m. scattering. Helium gas is used as the analyzer. Scintillation counters using 4 mil CsI crystals as well as nuclear emulsions have been used as detectors of the doubly scattered protons. The scattering angle in helium for a central ray is 75° c.m. Instrumental effects have been checked by running with xenon in the second chamber instead of helium, and by inverting it. Background was corrected for by alternating runs with vacuum or helium in the second chamber. The equipment is being further checked by substituting helium for deuterium. White, Chisholm, and Brown find an $n,D$ polarization of $+0.86\pm0.19$ for a neutron energy of 3.1 Mev and 90° c.m. scattering angle. Charge independence of nuclear forces implies equal polarizations for $n,D$ and $p,D$ elastic scattering if Coulomb effects can be neglected. This should be true for these experimental conditions. Our value for the $p,D$ polarization is $-0.12\pm0.07$.

* Partially supported by a grant from the National Science Foundation.
† On leave from the Aeronautical Research Laboratory.

**WA12. Continuous Polarization of H and D Atoms.*** W. R. BENNETT, JR., H. G. ROBINSON, AND V. BELTRAN-LOPEZ, *Yale University.*—A 200-cm³ bulb filled with $H_2$ and $D_2$ at partial pressures $<1\ \mu$ Hg and Na at $\sim10^{-7}$ mm Hg was used. High purity helium ($<1:10^8$ of most contaminants) at 40 cm Hg was added as a buffer gas. The products from a continuous rf discharge at the wall were allowed to diffuse into an electric field-free viewing region at the center of the sample. Intense Zeeman transitions were observed at frequencies corresponding to H and D atoms and to the free electron in a weak magnetic field. Identification of the H and D atom resonances was made by the observation of their respective Zeeman splittings. Multiple quantum transitions for these species were also seen. The various collision mechanisms appropriate to this mode of operation will be discussed.

* This work was supported in part by the U. S. Army Signal Corps.

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## SATURDAY AFTERNOON AT 1:45

Governor Clinton Hotel

(R. PEPINSKY presiding)

### *Ferroelectrics*

**X1. Evidence for Four Additional Phase Changes for Cadmium Niobate above the Curie Point.** A. DEBRETTEVILLE, JR., AND ROBERT M. OMAN, *U. S. Army Signal Research and Development Laboratory.*—Four additional phase changes, from room temperature to the Curie point at $-80$°C, were found in hot pressed $Cd_2Nb_2O_7$.[1] These can be shown by plotting the following data as a function of temperature; free energy and maximum polarization both obtained from hysteresis loop oscilloscope data, dielectric constant from bridge measurement data, and harmonic analysis data. Below room temperature, the data given show changes in slope or breaks at $-12$°, $-47$°, $-68$°,[1] $-76$°, and $-80$°C. The heats of transition as determined from free energy *vs* temperature plots are 0.39, 0.75, 1.2, 5.2, and 18 cal/mole. The latter is in agreement with the previously determined calorimetric value of $18\pm2$ cal/mole.[2] If these phases indicate some form of weak ferroelectricity and the phase transition temperatures are Curie points, then it can be expected that the material will be nonlinear above the $-80$°C Curie point. A nonlinear behavior of the dielectric constant was found by using harmonic analysis which is more sensitive than bridge or oscilloscope techniques. Nuclear magnetic resonance at room temperature exhibited quadrupole interaction of the niobium nucleus with the internal field, further substantiating that the material is ferroelectric above its formerly known Curie point of $-80$°C.

[1] deBretteville, Halden, Vasilos, and Reed, J. Am. Ceram. Soc. **40**, 88 (1957).
[2] H. R. Danner and R. Pepinsky, Phys. Rev. **99**, 1215–1217 (1955).

**X2. Absolute Configuration of Ferroelectric Crystals. I. Tetragonal $BaTiO_3$.*** Y. OKAYA, R. PEPINSKY, AND F. UNTERLEITNER, *The Pennsylvania State University.*—Pepinsky and Okaya[1] have pointed out that the absolute configuration of tetragonal ferroelectric $PbTiO_3$ could be established from a map of the function $P_s(u)=\sum\Delta F_H{}^2\sin2\pi H\cdot u$, when MoK$\alpha$ x-rays are employed. A program for determination of absolute configurations of several ferroelectric structures is in progress, using such anomalous dispersion effects. The structure of tetragonal $BaTiO_3$ has been established by neutron diffraction, and shifts from cubic positions accurately determined. No evidence of the direction of these shifts with respect to an applied field is achievable with neutrons. Using CoK$\alpha$ x-rays to excite the barium ions, clearly observable differences $\Delta F_H{}^2=|F_H{}^2|-|F_{-H}|^2$ are obtained. The signs of these agree well with the model based on the assumption that the Ti ion moves in the field direction.

* Research supported by Signal Corps Engineering Laboratories, U. S. Atomic Energy Commission, and Air Force Office of Scientific Research (ARDC).
[1] R. Pepinsky and Y. Okaya, Proc. Natl. Acad. Sci. U. S. **42**, 289 (1956).
[2] Frazer, Danner, and Pepinsky, Phys. Rev. **100**, 745 (1955).

**X3. Space Charge, Conductivity, and Electric Fields in $BaTiO_3$.** S. TRIEBWASSER, *IBM, Poughkeepsie.*—A number of investigators have reported contradictory anomalous behavior in $BaTiO_3$ crystals such as space charge layer effects, biased hysteresis loops and persistent polarization above the

Curie point.[1,2] It has also been reported that under some circumstances, application of a dc field to these crystals results in an unstable situation manifested by the build-up of internal space charge that tends to cancel the applied field. A number of experiments have been performed in which dc fields have been applied to crystals and their effect on hysteresis loops, nonlinear dielectric behavior, conductivity and induced birefringence have been observed. It is demonstrated that the latter effect (induced birefringence) can constitute a useful probe of macroscopic electric fields in crystals. A number of interesting results are obtained such as: rectification by an apparently symmetric structure; and induced birefringence and dielectric nonlinearity which are a function of the sign of the applied field in a cubic crystal. The data indicate that the difficulties that have been experienced by people attempting to utilize the hysteresis properties of $BaTiO_3$ originate not only in the electrodes but in the bulk of the material.

[1] K. Husimi, J. Appl. Phys. **29**, 1379 (1958); Kiyasu, Husimi, and Kataoka, J. Phys. Soc. Japan **12**, 433 (1957).
[2] A. G. Chynoweth, Phys. Rev. **102**, 705 (1956).

**X4. Preparation and Dielectric Properties of Boracite-Like Compounds.** F. JONA, *Westinghouse Research Laboratories.*—This investigation is concerned with the preparation and the study of compounds with the general formula $5MO \cdot 7B_2O_3 \cdot 1MCl_2$, where M is a divalent metal. For M = Mg, the compound is the mineral boracite, whose potential interest as a possible ferroelectric was first pointed out by Cady[1] and recently confirmed by LeCorre.[2] Natural crystals undergo a transition at 275°C, being cubic ($a = 12.1$ A, $Z = 8$, space group $T_d^5 - F\bar{4}3c$) above and polar orthorhombic ($a = b = 8.54$ A, $c = 12.07$, $Z = 4$, space group $C_{2v}^5 - Pca$) below the transition.[3] Ceramic specimens of Mg boracite were prepared and showed a small anomaly of the dielectric constant at approximately 260°C. The syntheses of Ni, Zn, and Cd boracite (M = Ni, Zn, Cd, respectively) were also successful. The transition points are 350°C for Ni, 453°C for Zn, and 525°C for Cd boracite, respectively, while the pseudocubic lattice constants are 12.10, 12.08, and 12.49 A, respectively. No ferroelectricity could be detected in ceramic specimens of these compounds.

[1] W. G. Cady, *Piezoelectricity* (McGraw-Hill Book Company, Inc., New York, 1946), p. 230.
[2] LeCorre, J. phys. radium **18**, 629 (1957).
[3] Ito, Morimoto, and Sadanaga, Acta Cryst. **4**, 310 (1951).

**X5. New Class of Ferroelectrics: Acid Selenites.*** R. PEPINSKY, K. VEDAM, Y. OKAYA, AND F. UNTERLEITNER, *The Pennsylvania State University.*—Optical observation of a reversible transition in potassium acid selenite has led to the dielectric examination of other acid selenites. Two new ferroelectric species have therewith been discovered: $LiH_3(SeO_3)_2$, ferroelectric at room temperature; and $NaH_3(SeO_3)_2$, ferroelectric below −75°C. $LiH_3(SeO_3)_2$ shows well-saturated square hysteresis loops over the temperature range from −190°C to +80°C. At room temperature the spontaneous polarization is 10.0 microcoulombs/cm², and the coercive field is 1.5 kv/cm. X-ray observations reveal monoclinic symmetry, space group $Pn$, with $a = 6.255$ A, $b = 7.899$ A, $c = 5.443$ A, $\beta = 105°23'$. The polar axis is perpendicular to the (001) plane. The material appears to be of practical importance. $NaH_3(SeO_3)_2$ is not isomorphous with $LiH_3(SeO_3)_2$. In the room-temperature phase the symmetry is monoclinic, space group $P_{21}/a$, with $a = 11.77$ A, $b = 4.84$ A, $c = 5.80$ A, $\beta = 118.5°$. The ferroelectric phase has triclinic symmetry (space group $P1$; if axes are denoted as for room-temperature phase, space group $C1$). The polar direction is along [310], referred to the monoclinic phase.

* Research supported by Air Force Office of Scientific Research (ARDC), Signal Corps Engineering Laboratories, and U. S. Atomic Energy Commission.

**X6. Phase Transitions in Hexafluophosphate Salts.*** K. VEDAM, R. PEPINSKY, JOSEPH LAJZEROWICZ, Y. OKAYA, AND N. STEMPLE, *The Pennsylvania State University.*—$NH_4PF_6 \cdot NH_4F$ is tetragonal at room temperature, and has two low-temperature transitions: at −45°C ($= T_{uc}$) and at −101°C ($= T_{Lc}$).[1] Both low-temperature phases are orthorhombic. The dielectric constant $\epsilon_{[110]}$ exhibits a small anomaly at $T_{uc}$, and a pronounced anomaly at $T_{Lc}$. X-ray examination reveals superstructuring along the $a$ and $b$ axes below $T_{uc}$, and a doubling of the $c$ axis below $T_{Lc}$. The lowest phase is antiferroelectric. A detailed structural investigation is required to reveal the dielectric character of the intermediate phase. An order-disorder transition has been observed in $KPF_6$ at 4°C.[1] A detailed x-ray structure analysis reveals hindered rotation of the $(PF_6)^{-1}$ octahedra. A large thermal anomaly at the transition temperature suggests a "freezing in" of the hindered rotations in the lower phase.

* Research supported by Air Force Office of Scientific Research (ARDC), Signal Corps Engineering Laboratories, and U. S. Atomic Energy Commission.
[1] R. Pepinsky *et al.*, Acta Cryst. **10**, 835 (1957).

**X7. Theoretical Model for Cubic to Tetragonal Phase Transformations in Transition Metal Perovskites.** PETER J. WOJTOWICZ, *RCA Laboratories.*—The large tetragonal distortions occurring in a number of transition metal perovskites have been explained recently by Dunitz and Orgel[1] in terms of the spatial ordering of Jahn-Teller type distortions in the immediate environment of certain transition metal cations. In this investigation we examine the detailed nature of the transformations from high to low symmetry phases by constructing an approximate model for the perovskites which explicitly takes into account the interactions between local J-T distortions about neighboring cations. The derivation of the properties of the model by the usual methods of statistical mechanics discloses that two kinds of cooperative ordering phenomena are possible depending on the sign of an interaction parameter $V$. For negative $V$, a single long-range order parameter is sufficient to describe the first order transformation to a low temperature tetragonal phase having $c/a > 1$. For positive $V$, two long-range order parameters are required to describe the resulting second-order transformation; the tetragonal phase in this case has $c/a < 1$ and doubled unit cell edges. The $c/a$ ratios quoted are for the prolate tetragonal J-T distortion; if the rare oblate distortion should obtain, then the inequalities are to be reversed.

[1] J. D. Dunitz and L. E. Orgel, J. Phys. Chem. Solids **3**, 20 (1957).

**X8. System $(BaNb_2O_6)_{100-x}$ $(BaZrO_3)_x$. I. Phase Equilibria.** R. S. ROTH, *National Bureau of Standards* (introduced by P. H. Fang).—The present study is concerned with the part of this system from $x = 0$ to $x = 50$. This portion of the system may be divided into three regions: (1) a two phase area containing $BaNb_2O_6$ and a B:N:Z solid solution; (2) a single phase solid solution area extending from a little less than 20 mole percent $BaZrO_3$ to a little more than 30 mole percent $BaZrO_3$; (3) a two phase area containing the B:N:Z solid solution and a cubic perovskite type $BaZrO_3$ solid solution. The compound $BaNb_2O_6$ is orthorhombic: $a = 12.19$ A, $c = 7.856$ A. No phase transformations have been found between 1200°C and the melting point, 1455±5°C. This compound has an x-ray diffraction pattern similar to the low-temperature nonferroelectric form of $PbNb_2O_6$, although of lower symmetry. A shallow eutectic apparently occurs in the two phase region at about 1445°C. The B:N:Z phase has a room-temperature structure similar to the polymorph of $PbNb_2O_6$ above the ferroelectric Curie point. It appears to be tetragonal, with a variation of lattice parameters with increasing $BaZrO_3$ content, at room temperature, of $b = 12.59$ A, $c = 4.002$ A to be $= 12.68$ A, $c = 4.007$ A. The phase equilibria

data suggest that this material is actually an incongruently melting compound $3BaO \cdot {}^3Nb_2O_5 \cdot ZrO_2$ with solid solution on the low $BaZrO_3$ side.

**X9. System $(BaNb_2O_6)_{100-x}$ $(BaZrO_3)_x$. II. Ferroelectric Properties.** P. H. FANG, W. S. BROWER, R. S. ROTH, AND S. MARZULLO, *National Bureau of Standards.*—The composition in this system where $x=25$ has recently been described by Goodman[1] to have interesting ferroelectric properties. In the solid solution region of this system which extends from $x=20$ to $x=30$, ferroelectric behavior is observed. The materials are ceramic and were prepared in disk form. At room temperature, the dielectric constant shows a saturation at high field of about 10 kv/cm, but no appreciable ferroelectric loop. When the temperature is lowered, the ferroelectric loop starts to appear, but both the spontaneous polarization and the coercive field increase only gradually, indicating a higher order ferroelectric transition. There is a broad dielectric peak in the temperature region of about −10°C where the hysteresis loop starts to appear, but x-rays cannot detect any indication of the phase transformation. At high temperatures, the dielectric saturation effect diminishes and above 100°C the polarization appears practically linear up to 20 kv/cm field strength. Where $x$ is either larger than 30 or smaller than 15, the material lies in two-phase regions and shows just ordinary dielectric behavior; no dielectric peak is found down to −40°C and no dielectric saturation is observed.

[1] G. Goodman, "Ferroelectric-paraelectric transition of higher than second order," Ceramic Society, Basic Science Division, September 29–30, 1958, Dayton, Ohio.

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## SATURDAY AFTERNOON AT 1:45

## Panel Room

## (K. T. BAINBRIDGE presiding)

### *Apparatus of Nuclear Physics; General Nuclear Physics*

**XA1. High-Resolution Iron-Free $\pi\sqrt{2}$ $\beta$ Spectrometer.** R. L. GRAHAM, G. T. EWAN, AND J. S. GEIGER, *Chalk River Laboratories.*—A high luminosity spectrometer ($\beta=\frac{1}{2}$) of 100-cm radius has been constructed according to the design calculations of Lee-Whiting.[1] These predict a resolution of 0.01% with a source 0.2 mm by 2 cm high and a transmission of 0.1% and a resolution of 1.0% with a source 2×5 cm and a transmission of 1.0% of 4 $\pi$. The magnetic field is generated by three pairs of coils with diameters approximately 155.6 in., 76.1 in., 35.5 in., half-spacings approximately 26.3 in., 31.4 in., 5.0 in., and 560, 236, and 128 turns per coil, respectively. The maximum current is 40 amp and the calibration is 393.29 gauss cm/amp. The earth's field is cancelled to $<10^{-2}$ gauss. In studies of the $Np^{239}$ conversion electron spectrum a line width of 0.013% has been achieved with a transmission of ~0.1% for the $L_1$ conversion line of the 228.1 kev $\gamma$ transition. The $K$ conversion lines are somewhat wider. Our results show that the natural width of the $Z=94$ $K$ level is 100±20 ev. Measurements on $L$ and $M$ subshell conversion lines from $Cs^{137}$, $Au^{198}$, and $Au^{199}$ will be reported.

[1] G. E. Lee-Whiting and E. A. Taylor, AECL Rept. CRT-668 (1956); Can. J. Phys. **35**, 1 (1957).

**XA2. A Proposal for Time-of-Flight Counters with $3\times10^{-11}$-sec Resolution.** DONALD I. MEYER, *University of Michigan.*—A great need exists for faster time-of-flight counters than those presently available when dealing with particles of energy greater than 1 Bev. The present limit on time resolution is set by the transit time spread of electrons in going through the photomultiplier structure. Microwave gating of the electron beam shortly after leaving the photocathode has been suggested as a method of timing which solves this problem and eliminates the attendant problem of fast coincidence circuits. Two or more counters gated in this manner from the same oscillator count only particles which pass through all counters with the right phase. This seems difficult to attain in practice. The suggestion made here is that the microwave electric field be applied directly to the photocathode. Various aspects of the problem such as photocathode heating, the velocity spectrum of the photoelectrons, and some preliminary experiments will be discussed. A practical device (now being constructed) which utilizes this principle will be described.

**XA3. A Gamma-Ray Sum Spectrometer Utilizing a Large Plastic Scintillator as an Anticoincidence Device.*** WILLIAM H. ELLETT, G. L. BROWNELL, AND S. ARONOW, *Massachusetts General Hospital.*—A 5-in. NaI well crystal is mounted coaxially within an inverted plastic well scintillator measuring 18×18 in. This arrangement allows the plastic scintillator to reject events coincident in both counters by gating off the signal from the NaI crystal to a 256-channel pulse-height analyzer. Coincident events include Compton interactions in the NaI crystal, cascade $\gamma$ emissions, and cosmic-ray background. The plastic scintillator is viewed by 4 5-in. photo multiplier tubes which can be operated in coincidence to reduce the effects of tube noise. The instrument is mounted in a 2-ton lead and mercury shield so that it can be used as a low-level counting device for the analysis of fallout products. Data will be presented on the effectiveness of the plastic well scintillator in improving the performance of the NaI crystal by: (a) reducing the Compton distribution, (b) increasing its efficiency as a sum spectrometer, and (c) reducing its background spectra.

* Supported by the U. S. Public Health Service.

**XA4. High-Efficiency, Relatively Low-Cost Gamma Detectors Using Gamma Moderation.*** RAYMOND FOX, *University of California, Livermore.*—It is often desired to count gammas in the energy range from approximately 0.5 to 5 Mev. In this region gamma detectors have a low reaction cross section. Theoretical and experimental results on the use of a gamma moderating medium to increase the efficiency of a gamma will be described. It is found that the use of a low atomic number moderating medium about the detector can increase greatly the detector's efficiency. Using a graphite moderator about a sodium iodide crystal and a $Co^{60}$ gamma source, an increased counting rate of 5.7 times was obtained. Uses and applications of gamma moderation will be described.

* This work was performed under auspices of the U. S. Atomic Energy Commission.

**XA5. Photomultiplier Operation.*** J. D. FOX AND A. SCHWARZSCHILD, *Brookhaven National Laboratory.*—In order to reduce the rate-dependent photomultiplier gain drifts and obtain the best possible resolution, the dynode and focusing

electrode characteristics of the Dumont 6363 3-in. diam. tube have been investigated. It is found that the gain drift is closely related to the average current drawn by the plate and may be minimized by lowering the over-all photomultiplier gain while increasing the external electronic amplification. Since the resolution depends strongly on the gain of the first stages, the potential between the photocathode and first dynode must be kept high and operation near 300 v is recommended. The focusing electrode is adjusted for maximum pulse height and it is found that the percent resolution is minimized in this way. When used with 3-in. diam. by 3-in. thick potted NaI(Tl) scintillators, we require 7.5% to 8.5% resolution for $Cs^{137}$ gamma rays. The focusing electrode characteristic is found to provide a convenient test for the Dumont 6363. Only those tubes whose pulse-height output follows a proper focusing electrode characteristic are capable of these resolutions. Characteristics of well and ill behaved tubes will be shown.

* Supported by the U. S. Atomic Energy Commission.

**XA6. Response of Unactivated Sodium Iodide to Protons, Deuterons, and Alpha Particles.** J. W. BLUE AND D. C. LIU, *Lewis Research Center*.—The discovery[1] that the yield of the 0.3-$\mu$ band of pure NaI, reported by Eby and Jentschke,[2] is enhanced by cooling to liquid nitrogen temperature has increased the usefulness of this material as a scintillator. The gain comes from the fact that the decay time is shorter than for activated NaI. Consideration of the possible uses of this scintillator has prompted a study of the pulse height *vs* energy dependence for various radiations. A linear dependence indicates the 0.3-$\mu$ band to be due to exciton capture or decay, whereas nonlinearity indicates the fluorescence arises from a process in competition with exciton creation. Curves of the pulse height *vs* energy for protons, deuterons, and alpha particles will be presented.

[1] W. Van Sciver, Nucleonics **14**, 50 (1956).
[2] F. S. Eby and W. K. Jentschke, Phys. Rev. **96**, 911 (1954).

**XA7. Positron Annihilation in Magnetized Iron.** W. D. MCGLINN.*† *University of Kansas*.—An attempt was made to describe the integral angular correlations for annihilation of polarized positrons in iron in a saturating magnetic field. A comparison with the experiment of S. S. Hanna and R. S. Preston[1] is made. The positron wave function used to calculate the angular coorelation for annihilation of $3s$, $3p$, and $3d$ electrons of iron was that obtained by a Wigner-Seitz calculation for zero crystal momentum, the potential in the Schrödinger equation being taken as the ion core potential. The inner electron wave functions were assumed to be those of free atomic iron. The angular correlation for the conduction electron annihilation was calculated assuming a degenerate fermi gas for the electrons and a zero-momentum wave function for the positron.

* Now at Northwestern University.
† Magnolia Oil Fellow.
[1] S. S. Hanna and R. S. Preston, Phys. Rev. **109**, 617 (1958).

**XA8. Absorption of 1-Bev Gamma Rays.*** E. MALAMUD, *Cornell University*.—The transmission of high-energy photons has been measured in various elements using a magnetic pair spectrometer for a detector. The energy dependence of the total cross section was measured in Copper from 400 to 1000 Mev. The $Z$ dependence at 1 Bev was determined by the attenuation in 12 elements from hydrogen to uranium. The results for medium and high $Z$ elements are in good agreement with the Davies-Bethe-Maximon[1] theory of nuclear pair production. Tentative results for low $Z$ absorbers are: hydrogen ($CH_2-C$ difference), $19.0\pm0.6$ mb; lithium, $99.2\pm2.2$ mb; beryllium, $167.1\pm1.7$ mb; carbon, $337.3\pm2.7$ mb. These results give information on pair production in the field of atomic electrons, and are in closer agreement to the theoretical predictions of Wheeler and Lamb[2] for this process rather than the estimate of Joseph and Rohrlich.[3]

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Davies, Bethe, and Maximon, Phys. Rev. **93**, 788 (1954).
[2] J. A. Wheeler and W. E. Lamb, Phys. Rev. **55**, 858 (1939); Phys. Rev. **101**, 1836 (1956).
[3] J. Joseph and F. Rohrlich, Revs. Modern Phys. **30**, 354 (1958).

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## SATURDAY AFTERNOON AT 1:45

Terrace Room

(C. A. BARNES presiding)

### *Invited Paper*

**Y1. General Situation of the Fundamental Constants.** J. W. M. DUMOND, *California Institute of Technology*. (40 min.)

### *General Physics*

**Y2. Proposed Test of the Nature of Gravitational Interaction.** HUSEYIN YILMAZ, *Sylvania Electric Products Inc.*—Following the recently proposed "New approach to general relativity,"[1] three possible field theories for gravity are constructed. These are the generally covariant scalar, vector, and tensor theories. Time-independent solutions to these theories are obtained by a method of successive approximation (scalar theory can be solved exactly) and it is seen that they predict the same results for the three crucial tests of general relativity. These three experiments appear to be at most the effects of general covariance and of geodetic postulate. To distinguish the nature of interaction, a different experiment must be considered. A possible experiment for this purpose is to launch an artificial satellite whose orbital plane contains the axis of rotation of the earth. If gravitation is a scalar interaction, this plane will stay fixed with respect to fixed stars. If the interaction is of a vector or tensor type, it will have a gradual precession around the axis of rotation of the earth amounting to about 56 sec of arc per century. The cause of the precession is that in a vector or tensor type, the *rotating earth* generates additional dynamical forces.

[1] H. Yilmaz, Phys. Rev. **111**, 1417 (1958).

**Y3. Test of Revised Electrodynamics.** V. O. NICOLAI, *Southern Illinois University*.—If the assumption is made that the entire energy within a differential in volume of space has

the same velocity, then the energy and momentum conservation laws lead to a revision of electrodynamics into a form which is invariant under a Galilean transformation. As a test of the validity of this revision an experiment is proposed. The experiment consists in shooting light between the conductors of a quarter-wave, 4-meter long, resonant rf transmission line. If 3.3 kilowatts of rf power are applied to the transmission line, a fringe shift of 0.001 wavelength is expected. This size of shift is just barely detectable by the very sensitive method due to Kennedy.[1]

[1] Illingworth, Phys. Rev. 30, 692 (1927).

**Y4. Origin and Spatial Distribution of Comets.** D. B. BEARD, *University of California, Davis.*—In their generally valid description of the equilibrium behavior of comets due to random collisions with planets and passing stars Oort and van Woerkom could not account for the observed high frequency of nearly parabolic comets. If one includes the effect of comet mass loss preferentially in the direction of the sun, however, one may conclude that comets during the visible part of their orbit appear to have much greater major axes than they do in fact possess. Indeed, from reasonable rates of mass loss proposed by Whipple, one can show that the reciprocal of a comet's major axis may appear to be greater by about $10^{-3}$ reciprocal astronomical unit than it actually is. The effect is proportional to the rate of mass loss times $(1+\cos\phi_1)$ where $\phi_1$ is the angle position of the comet where the material evolution from the comet begins. Thus this effect, depending as it does on the rate of mass loss and the solar distance at which mass loss takes place, is expected to change with comet "age" in such a direction in time as to favor the incidence of supposedly parabolic orbits.

**Y5. Magnetic Field Strength in the Crab Nebula.** HOWARD LASTER AND ALLEN LENCHEK, *University of Maryland.*—Mayer[1] has observed a polarization of about 7% for microwaves of 9500 mc emitted from the Crab Nebula. This compares with mean polarizations of about 17% and more for continuous light observed by Oort and Walraven.[2] If polarization of the continuous emission is caused by synchrotron radiation as many have suggested,[1-3] many factors tend to lower the polarization for lower frequencies. One important factor is Faraday rotation. The existence of polarization at 9500 mc sets upper limits on the average of the product of magnetic field times ionization within the Crab Nebula. The ionization can be estimated and upper limits therefore placed on the total magnetic energy in the Crab. Since the limits depend upon certain assumptions about the structure of the field, the validity of these assumptions is discussed.

[1] Mayer, McCullough, and Sloanaker, Astrophys. J. 126, 468 (1957).
[2] Oort and Walraven, B.A.N. 12, 285 (T. 1956).
[3] Shklovsky, Compt. rend. acad. Sci. U.S.S.R. 90, 983 (1953); Ginzburg, Nuovo cimento Suppl. 111, No. 1 (1956); Baade, B.A.N. 12, 312 (1956); Burbidge, Astrophys. J. 127, 48 (1958).

**Y6. Suggested Method for Measurement of Solar-Interplanetary Magnetic Fields.** ALLEN M. LENCHEK, *University of Maryland* (introduced by H. Laster).—Several factors, notably solar corpuscular beams, produce asymmetries in the magnetic fields of the interplanetary medium. The plane of polarization of radio emission from the Crab Nebula[1] may therefore undergo a nonzero net Faraday rotation in crossing the solar system. Certain features of these fields may be directly observable by measurement of transient rotations of the plane of polarization. A solar beam carrying a nonturbulent longitudinal field, with properties such as postulated by Alfven,[2] is predicted to give easily observable rotations when the earth, sun, and Crab Nebula are close to being colinear. The effects of several models of solar-interplanetary fields will be discussed.

[1] Mayer *et al.*, Astrophys. J. 126, 468 (1957).
[2] Alfven, Tellus 8, 1 (1956).

**Y7. On the Relationship between the Atomic Weights of Chief Isotopes of the Elements of He and Ne Periods.** N. EFREMOV, *1061 Intervale Avenue, New York, New York.*—It is generally believed that there is no distinct regularity between the atomic weights of isotopes in a successive series of elements. But if we consider the mass differences between the atomic weights of the chief isotopes of the elements belonging to the He-period and assume the mass difference between $B^{-11}$ and $C^{-12}$ as the center of He-period, we will find symmetry between the left side figures (3, 2, 2) of mass differences and the right.

| Elements: | He | Li | Be | B | C | N | O | F |
|---|---|---|---|---|---|---|---|---|
| Chief isotopes: | 4 | 7 | 9 | 11 | 12 | 14 | 16 | 19 |
| Mass differences: | | 3 | 2 | 2 | 1 | 2 | 2 | 3 |

There is the same symmetry of mass differences between the atomic weights of chief isotopes of the Ne-period.

| Elements: | Ne | Na | Mg | Al | Si | P | S | Cl |
|---|---|---|---|---|---|---|---|---|
| Chief isotopes: | 20 | 23 | 24 | 27 | 28 | 31 | 32 | 35 |
| Mass differences: | | 3 | 1 | 3 | 1 | 3 | 1 | 3 |

**Y8. Dielectric Constant of Liquids.** A. ISHIHARA, *Polytecknic Institute of Brooklyn.*—The contribution of the rotational fluctuation to the dielectric constant of liquids is important for liquids composed of nonspherical molecules. Following the theory of Kirkwood and the group theoretical method developed by the author, a general expression for the contribution will be given. A particular case of ellipsoidal molecules will be discussed.

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## SATURDAY AFTERNOON AT 1:45

## Boston Room

(W. W. WATSON presiding)

### *Spectroscopy*

**Z1. Mass Attenuation Coefficients for Elements of Low Atomic Number and Energy.** ALAN J. BEARDEN, *The Johns Hopkins University.*—Precision mass attenuation coefficients have been measured for elements of low atomic number in the energy range from 2.984 to 8.047 kev. A vacuum double crystal monochromator using quartz crystals of high dispersion and resolving power $CuK(1-1)=4.65$ sec and $MoK=2.7$ sec effectively eliminated errors that resulted from scattering of the continuous radiation. High-efficiency proportional counters with single-channel discrimination made background corrections unnecessary. Metal absorbers of the highest purity were made into uniform foils, and the pure gases were contained in

TABLE I.

| kev | 8.047 | 6.200 | 5.414 | 5.510 | 3.444 | 2.984 |
|---|---|---|---|---|---|---|
| $H_2$ | 0.546 | 0.719 | 0.856 | 1.17 | 2.15 | 2.60 |
| He | 0.284 | 0.345 | 0.494 | 0.684 | 1.33 | 2.00 |
| Be | 1.76 | 2.29 | 3.70 | 6.25 | 15.0 | 22.8 |
| C | 4.33 | 8.79 | 15.2 | 25.0 | 60.9 | 89.4 |
| $N_2$ | 7.29 | 15.0 | 25.1 | 44.5 | 99.5 | 149 |
| $O_2$ | 11.8 | 25.3 | 41.1 | 69.1 | 156 | 223 |
| Ne | 22.0 | 44.7 | 76.0 | 130 | 282 | 421 |
| Al | 51.6 | 92.4 | 149 | 244 | 541 | 774 |
| A | 118 | 274 | 422 | 667 | 1470 | 203 |

a stainless steel absorption cell with Mylar windows. The measured mass attenuation coefficients ($cm^2/g$) are shown in Table I.

**Z2. Stark Effect Profiles of Some Hydrogen Lines.*** H. GRIEM, *University of Maryland and U. S. Naval Research Laboratory*, A. C. KOLB, *U. S. Naval Research Laboratory*, AND K. Y. SHEN, *University of Maryland*.—The profiles of the first two Lyman lines and the first four Balmer lines have been calculated for a range of electron densities and temperatures where Doppler broadening is negligible, but where the lines are still separated. The electron contribution to the broadening was treated by means of a recently developed impact theory for nearly degenerate quantum mechanical systems.[1,2] For the ion effects the quasi-static approximation was used with ion field strength distribution functions corrected for correlations between the perturbers. The temperature dependence of the line shapes is usually so small, that electron densities can be derived from measured profiles also when temperatures are unknown or thermal equilibrium is questionable.

* Jointly supported by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] M. Baranger, Phys. Rev. 111, 494 (1958).
[2] A. C. Kolb and H. Griem, Phys. Rev. 111, 514 (1958).

**Z3. Optical Line Shapes from Ionized Gases.*** BERNARD MOZER AND MICHEL BARANGER, *Carnegie Institute of Technology*.—A recent theory of pressure broadening[1] has been used to calculate the shape of some hydrogen and helium lines emitted in hot ionized gases. The method assumes that the ionic field splits the line by Stark effect. Then the electron broadening of the resulting Stark pattern is calculated by the impact theory, account being taken of the overlapping of the individual components. Some divergent integrals occur, but it can be shown that they should be cut off near a value of the impact parameter equal to the Debye length. The result is integrated with the probability distribution of the ionic field. The latter is a Holtsmark distribution suitably modified for the correlation among the ions. The Doppler effect is also folded in. Numerical results will be given for various values of the temperature and ion density.

* Supported by the Office of Naval Research.
[1] M. Baranger, Phys. Rev. 111, 494 (1958) and to be published; A. C. Kolb and H. Griem, Phys. Rev. 111, 514 (1958).

**Z4. High-Resolution Doppler and Isotopic Shift Spectrometry Using an Atomic Beam Light Source.** D. G. HUMMER, W. L. FITE, AND R. T. BRACKMANN, *General Dynamics Corporation*.—The shape of the $O_2$ transmission band at 1216 A has been investigated using Lyman-alpha radiation emitted from chopped atomic beams of hydrogen and deuterium under electron impact. A movable iodine-vapor-filled photon counter[1] equipped with a continuous flow oxygen cell was used to detect the radiation coming from the intersection point of the atomic and electron beams. The Doppler shift arising from the known beam velocity, at various angles of observation, was used to provide a monochromator of extremely high angular dispersion over a wavelength range of 0.08 A about both hydrogen and deuterium Lyman alpha. Various factors contributing to the Lyman-alpha line shape are considered and indicate the method has a resolution in excess of 500 000. It is found that the absorption coefficient of oxygen for deuterium Lyman-alpha exceeds that for hydrogen Lyman alpha by $0.08 \pm 0.02$ $cm^{-1}$ and no structure in the oxygen absorption spectrum is found in the immediate neighborhood of either of the two Lyman alphas.

[1] Brackmann, Fite, and Hagen, Rev. Sci. Instr. 29, 125 (1958).

**Z5. Long-Range Repulsive Intermolecular Forces.** W. W. ROBERTSON AND A. D. KING, JR., *University of Texas*.—The effects of a diluent on the electronic energy levels of a light absorber are generally understood in terms of long-range dispersion forces. Since the dispersive interaction is usually greater for the absorber in an excited state than in the ground state, spectral shifts are to the red. However, the vapor absorption spectrum of benzene in the near ultraviolet is found to shift to the blue with increasing density of the diluent helium. The approximate linearity of the blue shift, starting at low helium densities, makes it improbable that the shift is due to a predominance of short-range repulsive forces. Since dispersive forces increase with increasing oscillator strength of absorber while repulsive forces do not, it was thought that by using condensed ring aromatics having transitions of widely different oscillator strengths, dispersive and repulsive forces might be separated and the nature of the benzene-helium interaction inferred. Thus the spectra of naphthalene, phenanthrene, and pyrene were observed in the diluents helium and nitrogen at pressures to a thousand atmospheres. The results indicate that the predominant interaction between benzene and helium is repulsive and of a long-range variety.

**Z6. Molecular Optical Collision Cross Section.*** HAROLD BABROV, GEORGE AMEER, AND WILLIAM BENESCH, *University of Pittsburgh*.—Cross sections for collisions between HCl and various other molecules have been determined from measurements of the widths of absorption lines of the $P$ branch of the fundamental vibration-rotation band of HCl. The strengths of the lines are obtained from a two part experiment in which the gas pressures are so chosen as to fix the Lorentz line shape parameters at values which enhance the sensitivity of the measured integrated absorption to the line strength.[1] With the strengths now known, the half-width of each line is determined from a single measurement of the integrated absorption of the line. Molecular collision cross sections are calculated from the line widths by the usual relationships. Cross sections for HCl-HCl and HCl-$N_2$ collision have been reported elsewhere.[2] Collision cross sections have now been measured using a group of colliding molecules chosen to include a considerable variety of interactions, and the data thus obtained emphasize the highly individual behavior of the $J$ dependence of the cross sections characteristic of these various foreign gases.

* This research was supported by the U. S. Air Force through the Office of Scientific Research.
[1] Babrov, Ameer, and Benesch, Symposium on Molecular Structure and Spectroscopy, The Ohio State University (June, 1957).
[2] Babrov, Ameer, and Benesch, J. Mol. Spectroscopy (to be published).

**Z7. Spectrum of a Krypton and Oxygen Mixture.*** E. L. TOLNAS, *University of Georgia* (introduced by C. D. Cooper).—A molecular spectrum was produced in an ozonizer-type discharge tube containing 1.3 atmos of krypton with 18 ppm of $O_2$. Four Mc/sec excitation was used. Molecular band structure and the 5577 A oxygen line were found in the green region. These band heads were at 5584, 5561.6, 5543.1, 5532,4. 5521.2, 5510.5, 5501.6, 5494.8, 5489.4, and 5482.3 A. The 2972 A oxygen line was found with a weak asymmetrical broadening effect which extended from 2964 to 3014 A with maximum intensity at 2981 A. As in the spectra of $A+O_2$ and $Xe+O_2$,[1] the band structure in the green region is attributed to a $Kr(^1S_0)O(^1S_0) \rightarrow Kr(^1S_0)O(^1D_2)$ transition and the asymmetrical broadening in the ultraviolet to a $Kr(^1S_0)O(^1S_0) \rightarrow Kr(^1S_0)O(^3P)$ transition. Excitation of atomic

($^1S_0$) oxygen could be produced upon collision of metastable ($^3P_2$) krypton with $O_2$ in a $(^3P_2)Kr+O_2 \rightarrow (^1S_0)Kr+(^1S_0)O+(^3P_2)O$ process. A strong continuum was also found and is assumed to be the continuum of high pressure krypton.[2]

* This research was supported in part by the Geophysics Research Directorate, Air Force Cambridge Research Center.
[1] C. D. Cooper and M. Lichtenstein, Phys. Rev. 109, 2026 (1958).
[2] S. Weniger, Ann. phys. 2, 410 (1957).

**Z8. Measured Transition Probabilities and Line Widths for $O_2$.*** C. E. TREANOR AND W. H. WURSTER, *Cornell Aeronautical Laboratory*.—Absorption measurements have been performed for transitions of the $v'=0$ sequence of the Schumann-Runge system of $O_2$, using shock-heated oxygen in the temperature range 2500 to 4500°K. A large Littrow quartz spectrograph was used, giving a dispersion of 6 A/mm in the near ultraviolet. Transition probabilities and line widths have been obtained for the separate rotational lines. The electronic $f$ values obtained are about five times less than that reported[1] for the continuum absorption in the far ultraviolet, corresponding to a decrease in $f$ value at large internuclear separation.[2] Line widths have been determined as a function of the partial pressure of molecular oxygen and atomic oxygen. The optical cross section for $O_2$-O collisions is 2.5 times that for $O_2$-$O_2$ collisions.

* Supported by the Combustion Dynamics Division of the Air Force Office of Scientific Research.
[1] R. W. Dichtburn and D. W. O. Heddle, Proc. Roy. Soc. (London) **A220**, 61 (1953); **A226**, 509 (1954).
[2] R. W. Nicholls, *Airglow and Aurorae* (Pergamon Press, London and New York, 1956), p. 302.

**Z9. Magnetic Hyperfine Structure in the Rotational Spectrum of Nitrogen Dioxide.*** JAMES C. BAIRD, JR.,† AND GEORGE R. BIRD,‡ *The Rice Institute*.—A rigid rotor analysis of the nitrogen dioxide microwave spectrum has been reported. The spectrum is found to consist primarily of multiplets of ten lines whose splittings are caused by the various magnetic interactions between molecular rotation, electron spin and nuclear spin. Lin and Van Vleck have developed a theory to treat this spectrum. The results reported here utilize this theory, our measurements, and those made by Rosenthal at New York University. For a given rotational state Lin and Van Vleck's theory gives a $6\times6$ secular equation [for $N^{14}O_2$, $(2S+1)(2I+1)=6$] which factors into two $2\times2$ and two $1\times1$ determinants. Hence, the energy expression for four levels contains quadratic expressions in the eight molecular parameters which characterize the interactions. Because of this complexity it is awkward to solve for these unknowns, even though sufficient information is contained within one rotational multiplet. Methods have been developed for extracting these parameters from the energy equations with the aid of solution paramagnetic resonance and isotope ($N^{15}O_2$) data. The resulting constants permit a consistant interpretation of the microwave spectrum and the gas-phase electron paramagnetic spectrum of Castle and Beringer.

* Work supported by the Research Corporation and the Robert A. Welch Foundation.
† Present address: Harvard University.
‡ Present address: Polaroid Corporation.

**Z10. Electronic Wave Functions for Polyatomic Molecules.** LELAND C. ALLEN, *Materials Research Laboratory, OMRO and M.I.T.*—A one-electron basis set made from functions with exponential and Gaussian radial dependence is proposed for constructing many electron, many center, electronic wave functions. A mixture of these two types is suggested which may greatly simplify the evaluation of many center, two-electron integrals and, in addition, lead to an improved physical description of the molecular bond. Plane waves also may be added readily to the basis set, thus making an application to solids feasible.

**Z11. Vibrational Relaxation Times in Oxygen.*** MORRIS SALKOFF, *Institut Henri Poincare, Paris*, AND ERNEST BAUER, *AVCO*.—In extension of earlier work,[1] we have used an existing program on a UNIVAC computer to calculate the cross section for vibrational excitation of an oxygen molecule by collision with another oxygen molecule. Our result, in the form of Blackman,[2] and is used to obtain an expression for the intermolecular potential which is presumably relatively reliable in the 0.1 to 0.5 ev energy range.

* This work was carried out at the Institute of Mathematical Sciences, New York University. It was supported in part by the U. S. Atomic Energy Commission.
[1] M. Salkoff and E. Bauer, J. Chem. Phys. 29, 26 (1958).
[2] V. Blackman, J. Fluid Mech. 1, 61 (1956).

## SUPPLEMENTARY PROGRAMME

**SP1. Alternative Theory of the Neutrino.** E. J. SCHREMP, *U. S. Naval Research Laboratory*.*—Our modified wave equations for a free spin ½ particle have previously been shown to possess *chiral* 8-component plane wave solutions $\psi_\pm(x)$, such that $\psi_+(x)+q(x)\psi_+(0)$ and $\psi_-(x)=\bar{q}(x)\psi_-(0)$, where $q(x)=\exp(i\omega^0\lambda)(e_0\cos\lambda+e\sin\lambda)$. Here $\lambda=P_kx^k/\hbar$, where $x^k$, $P^k(k=0,1,2,3)$ are the particle's coordinates and momenta; while $i\omega^0$ is the imaginary scalar part, and $e$ the (generally complex) unit vector part ($e^2=-e_0$), of a constant quaternion $\omega=q^{-1}(dq/d\lambda)=(dq/d\lambda)q^{-1}=ie\omega^0+e$. For the neutrino, for which $m=0$, our fere-particle equations reduce to $\square_\mp\psi_\pm=0$, and hence to $\square_-q=0$. Since $\square_-q=(\square_-\lambda)(dq/d\lambda)=P\omega q/\hbar$, where $P=e_0P^0+i(e_1P^1+e_2P^2+e_3P^3)$, we therefore must have $P\omega=0$, with the following consequences for the neutrino: (1) $P_kP^k=0$; (2) $e=(\omega^0/P^0)(e_1P^1+e_2P^2+e_3P^3)$; and (3) $(\omega^0)^2=1$. Consequences (2) and (3) provide an alternative description of the chiral properties of the familiar 2-component neutrino; but they do so in an 8-component representation in which the neutrino wave function $\psi_\pm$ (in analogy with the wave function of an isodoublet) corresponds to a $2\times4$ matrix $\psi=\|\nu\gamma_5\nu^c\|$, involving a 4-spinor $\nu$, with charge conjugate $\nu^c$, that is subject to the unimodular unitary transformations of Pauli, but to *no* subsidiary Majorana reality condition.

* To be given at the end of Session T if the Chairman rules that time permits.

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Suddeth, J. A.—S2
Suh, Kiu S.—D13
Sunyar, A.—VA7
Symon, K. R.—V8

Taft, E. A.—J8, S7
Tanenbaum, M.—J5
Tannenwald, L. M.—PA4
Tanner, E. C.—F11
Teare, J. D.—F3
Tell, B.—WA10
Teller, Edward—HA1

**Tendam, D.[1]J.**—EA7, EA8
**Theimer, O.**—SA8, SA9
**Thomas, G. E.**—M10
**Thomas, John J.**—J11
**Thorndike, E. H.**—WA7
**Tinkham, M.**—B10
**Tollestrup, A. V.**—C12, MA1
**Tolnas, E. L.**—Z7
**Townes, C. H.**—L3
**Traub, J.**—D5
**Treanor, C. E.**—Z8
**Trees, R. E.**—D4
**Triebwasser, S.**—X3
**Tripp, R.**—H4
**Truong, T. N.**—P2
**Turkevich, A.**—K5
**Turkot, Frank**—GA2

**Unterleitner, F.**—X2, X5
**Uram, Earl M.**—F12

**Van De Graaff, R. J.**—V1
**Vanderbosch, R.**—C11
**Van Kranendonk, J.**—RA4
**Van Patter, D. M.**—K8, K9
**Vasileff, H. D.**—N4
**Vaughn, M. T.**—P1
**Vedam, K.**—X5, X6
**Vitkovitsky, I. M.**—F1, F2
**Voorhies, H. G.**—PA7, PA8

**Waggoner, J.**—GA1
**Wagner, M. D.**—S2
**Wagner, P. E.**—G5
**Wagoner, G.**—G10
**Waldman, B.**—WA3
**Wales, W.**—GA5
**Walker, R. L.**—GA5, H1
**Walker, W. D.**—GA6
**Warburton, F. W.**—W13
**Warschauer, D. M.**—S9
**Watson, M.**—H4
**Watson, W. K. R.**—JA7, JA8
**Watson, W. W.**—M6
**Watts, T. L.**—U3
**Weill, R.**—GA3
**Weneser, J.**—W9
**Wentworth, R. C.**—BA6, BA7
**Wenzel, R. F.**—PA7
**Wertheim, G. K.**—J4
**Weisskopf, V. F.**—KA1
**Wescott, C. H.**—M1
**Weston, L. W.**—R4, R5
**Westrum, E. F., Jr.**—B1
**Wetstone, D. M.**—PA12
**White, J. A.**—CA3
**White, R. Stephen**—H3
**Whitehead, Marian N.**—H8, H9
**Whitfield, G. D.**—N5
**Wilcox, John M.**—V10
**Wilkinson, D. H.**—VA3
**Williams, Dudley**—CA7
**Williams, G. A.**—CA5
**Williams, Roscoe C.**—J11
**Wilson, Richard**—WA7, WA8, WA9
**Wilson, W. E.**—R11
**Wojtowicz, Peter J.**—X7
**Woodbury, H. H.**—G8, G9
**Wright, W. B.**—JA2
**Wurster, W. H.**—Z8

**Yafet, Y.**—J2
**Yearian, M. R.**—WA6
**Yevick, G. J.**—E8, E9
**Yilmaz, Huseyin**—Y2
**Yntema, J. L.**—C3, C9, EA4
**Yokosawa, A.**—R6
**Young, O. B.**—BA8

**Zeidman, B.**—C3, C9
**Zimmerman, R. L.**—M1, M12
**Zucker, A.**—PA5, U5

## Hotel Information

The New Yorker is the headquarters hotel. Reservations should be sent directly to Mr. Thomas Hurd, Front Office Manager of the New Yorker, in the manner directed below. Please tear off the attached and use as your room reservation blank. Be sure to specify the persons for whom reservations are being made. All rates quoted are for the room, and in the event of more than one person occupying the room the rate can be shared. If a third person is housed in the room, the cost of the extra "roll-away" bed will be added to the cost of the room.

If a room at the rate requested is not available, one at the nearest available rate will be reserved for you. Be sure to bring the confirmation slip with you as proof of your reservation. In fairness to others, please make a cancellation if your plans change. Unless otherwise requested, the hotel will hold reservations only to 6 P.M. of the day of your arrival. Check-out time is 3 P.M.

## Hotel Rates

| Hotel | Room and Bath for one per day | Double-Bed Room with Bath for two per day | Twin-Bed Room with Bath for two per day | Suites Living Room Bedroom and Bath for one or two per day |
|---|---|---|---|---|
| **New Yorker** 34th Street at 8th Avenue | $8–$14.50 | $11.50–$18.00 | $15.50–$20.00 | $35.00 and up |

NOTE: All rates subject to New York City 5% hotel room tax.

Tear Off

Tear Off

To: Front Office Manager
Hotel New Yorker
34th Street and 8th Avenue
New York, New York

**A.P.S.**

Please enter my reservation for a single / double / twin bedroom at approx. $..... to $..... per day for the 1958 A.P.S. Meeting. I / We plan to arrive..... and remain until .....

Print below persons in your party.

.....
Signature

.....
Address (Street or P.O.)

.....
Town or City and State

## Second Announcement of the 1959 Southwestern Meeting

The Southwestern meeting, reinstated after a lapse of one year, will be held in 1959 on Friday, March 6, and Saturday, March 7, at the University of Texas in Austin. Hotels mentioned by the Local Committee are the Commodore Perry, the Driskill, and the Stephen F. Austin. Deadline day is Friday, January 9, and abstracts are to be sent to Karl K. Darrow, *Secretary*, American Physical Society, Columbia University, New York 27, New York. ***Please be careful to mark your abstracts for the Southwestern or Austin meeting, as deadline for the Cambridge meeting arrives only a week later.***

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## Preliminary Announcement of the 1959 Cambridge "March" Meeting

A meeting of the American Physical Society will be held on March 30, 31, and April 1, 1959. In describing it we encounter great difficulties. This will be one of the sequence commonly called "March meetings," and yet it is only partly in March and there is a different meeting wholly in March. The sessions will be held in one city, at M.I.T. in *Cambridge*, but the official hotel will be in another city, for it will be the Somerset Hotel in *Boston*. To complete the deviations from rule, the meeting will be held on *Monday, Tuesday, and Wednesday*. Nevertheless it is the 1959 exemplar of the well-known March meetings at which our Divisions of High-Polymer Physics, Solid-State Physics, and Chemical Physics play the major roles. Deadline will be Friday, January 16, and the abstracts are to be sent to Karl K. Darrow, *Secretary*, American Physical Society, Columbia University, New York 27, New York. *If you are as prompt as you should be in mailing your abstract, mark it for the Cambridge meeting*, for deadline for the Austin meeting arrives only a week earlier, and if you forget you may find yourself giving your paper in Texas (not, however, an unpleasant prospect). Make your reservation at the Somerset Hotel, Boston, Massachusetts, as early as you can.

## Minutes of the Conference on Weak Interactions Held at Gatlinburg, Tennessee, October 27, 28, and 29, 1958

ON October 27, 28, and 29, the American Physical Society joined with the Oak Ridge National Laboratory in sponsoring a Conference on Weak Interactions, which was held in autumnal atmosphere at Gatlinburg, Tennessee. The subjects under discussion ranged from contemporary experiments and conclusions regarding beta decay through the implications of the weak interactions among the decay modes of mesons and hyperons. In a group with such specialized common interest, there was lively interplay between experimentalists and theoreticians. An unprogrammed evening session, in which four essentially simultaneous measurements of the rare $\pi$-$e$ decay mode were reported and compared, was perhaps especially noteworthy in this respect. Ten invited papers were presented, the substance of which will be published in an early issue of the *Reviews of Modern Physics* (tentatively, the issue of April, 1959), while the abstracts of the forty-five contributed papers are printed below. Supplementary papers received too late to be included in the preconference bulletin are printed with the session at which they were presented. Opportunity was offered for all abstracts to be corrected and brought up to date as of October 29, 1958.

On the second afternoon of the Conference, cloudless weather invited the 185 registrants to avail themselves of bus trips and hikes in the Smoky Mountains, from which they returned to refreshments that had been provided through the generosity of the Union Carbide Nuclear Company. The Program Committee for the Conference consisted of the following: J. L. Fowler, A. I. Galonsky, E. J. Konopinski, M. E. Rose, T. A. Welton, H. B. Willard, C. S. Wu, and the undersigned.

ARTHUR H. SNELL
*Chairman*

**B1. Longitudinal Polarization of β-Decay Electrons.** H. BIENLEIN, K. GÜTHNER, H. v. ISSENDORFF, AND H. WEGENER, *Universität Erlangen.*—$P_{\text{long}}$ of $\beta$-decay electrons was measured by Mott scattering after deflection in a spherical electric field.[1] We carefully took into account disturbances by depolarization in the source, plural scattering in the gold scattering foil, nonuniformity of the foil, and backscattering of the walls. The apparatus asymmetry, tested by aluminum foils, was eliminated by moving the source, and so perturbations caused by different angular and energy dependences of Au and Al were avoided. Assuming that there is full polarization for $Co^{60}$ electrons, we measured Sherman's $S$ function (which is calculated without screening) and found: $S_{\text{exp}}/S_{\text{theoret}}=\xi=0.86\pm0.02$; $0.96\pm0.02$ and $1.00\pm0.02$ for $v/c=0.58$ (120 kev), 0.64 (155 kev), and 0.70 (207 kev). There is no influence of screening for the greatest energy. For $v/c=0.58$, Mohr and Tassie[2] found theoretically $\xi=0.87$ in accordance with our result. After measuring the $S$ function we started with polarization measurements of RaE electrons. For energies 120, 155, 209, and 290 kev we find that $P_{\text{long}}/(-v/c)=0.69\pm0.04$, $0.75\pm0.04$, $0.75\pm0.04$, and $0.66\pm0.06$. These values are somewhat higher than theoretical predictions according to the best fit of the spectrum.[3]

[1] Bienlein, Günther, v. Issendorff, and Wegener, Nuclear Instr. (to be published).
[2] C. B. O. Mohr and L. J. Tassie, Proc. Phys. Soc. (London) **A67**, 711 (1954).
[3] Bincer, Church, and Weneser, Phys. Rev. Letters 1, 95 (1958).

**B2. Measurement of the Longitudinal Polarization of β Particles from $P^{32}$ Decay.** B. H. KETELLE, A. R. BROSI, A. GALONSKY, AND H. B. WILLARD, *Oak Ridge National Laboratory.*—Longitudinal spins of $\beta$ particles are precessed by deflection through 136° in a spherical electrostatic spin rotator. The transverse component of polarization is analyzed by 135° Mott scattering from thin gold foils. Scattered electrons are detected with two multichannel anthracene scintillation spectrometers. The 624-kev $Cs^{137}$ $K$-conversion line shows that this rotator has an energy resolution of 4%, and a transmission of $\sim10^{-4}$ for a $\pm6°$ azimuthal acceptance angle at the source. $P^{32}$ source strengths of 60 and 1200 millicuries (0.3 and 4 mg/cm², respectively, and 2 mm in diameter) were used for measurements at 624 kev ($\beta=0.89$). For a 1.00 mg/cm² gold scattering foil the weak and strong sources gave, respectively, scattered electron asymmetry ratios of 0.562 $\pm0.007$ and $0.575\pm0.004$. The strong source was used also with gold foils of 0.44, 0.32, and 0.19 mg/cm² giving $0.516\pm0.005$, $0.516\pm0.003$, and $0.503\pm0.003$, respectively. The observed source thickness dependence was used to correct the above values to $0.504\pm0.009$, $0.504\pm0.008$, and $0.491\pm0.008$. By extrapolation to zero foil thickness we obtain an asymmetry of $0.480\pm0.010$. Correcting for our finite geometry and using Sherman's calculations for the Mott scattering asymmetry, the polarization of 624-kev $P^{32}$ electrons is then found to be $(-1.00\pm0.03)\,v/c$.

**B3. Mott Scattering Analysis of Longitudinal Polarization of Electrons.*** D. P. MALONE, J. S. GREENBERG R. L. GLUCKSTERN, AND V. W. HUGHES, *Yale University.*—The use of the Mott scattering method and the influence of some of its inherent systematic errors on the measurement of the polarization of 128-kev electrons from $Cs^{137}$ and $Co^{60}$ were discussed in a previous communication.[1] The low asymmetries that were measured have encouraged a further investigation into the systematic errors in the experiment. Depolarization in the source material and backing has been studied and in addition a more thorough investigation has been made into the effects of finite scatterer thickness on the measured asymmetry. The former effect had not been previously taken into account. With all known corrections applied, the polarization of 200-kev electrons from $Co^{60}$ was found to be $-(1.03\pm0.95)(v/c)$. The screening correction has not been calculated at this energy. A preliminary measurement performed on RaE (200 kev) has yielded a value for $P=-(0.43$

$\pm 0.25)(v/c)$. The latter does not include back-scattering corrections.

* This research was initially supported in part by the office of Naval Research.

[1] Greenberg, Hughes, Quinton, and Malone, Bull. Am. Phys. Soc. Ser. II, 3, 52 (1958).

**B4. Longitudinal Polarization of Electrons from Holmium-166.*** T. A. POND, W. A. W. MEHLHOP,† AND E. D. LAMBE, *Washington University.*—A comparison of the longitudinal polarization of the beta-particles from P-32 and 27 hr Ho-166 has been undertaken. Earlier work[1] has shown that the polarization in P-32 is $-(v/c \pm 6\%)$. Ho-166 decays in two branches of about equal intensity with endpoints that differ from P-32's by less than 10%. One branch is first forbidden, unique, and may be assumed to show polarization $-v/c$. The other is first forbidden, $A$ or $P$. The comparison is made by Møller scattering with a geometry similar to Frauenfelder's.[2] The scatterer is 3.6 mgm/cm² Supermendur magnetized to saturation (about 14 500 gauss) and mounted at 30° to the incident beam. Pairs of scattered and struck electrons with energies greater than 330 kev emerging from the foil at $(31 \pm 6)°$ to the direction of the incident beam are detected by two plastic scintillation spectrometers with fast-slow coincidence electronics. The change in counting rate when the magnetic field is reversed, after subtraction of the experimentally determined background, is $(8.41 \pm 0.38)\%$ for P-32, and $(8.14 \pm 0.73)\%$ for Ho-166. The electron helicity is negative in both cases.

* Supported by the U. S. Air Force, Office of Scientific Research.
† Bell Telephone Predoctoral Fellow.

[1] Benczer-Koller, Schwarzschild, Vise, and Wu, Phys. Rev. 109, 85 (1958); Geiger, Ewan, Graham, and MacKenzie, Phys. Rev. (to be published).
[2] Frauenfelder, Hanson, Levine, Rossi, and de Pasquali, Phys. Rev. 107, 643 (1957).

**B5. Longitudinal Polarization of Positrons from Neon-19.*** E. D. LAMBE, J. B. REYNOLDS, J. JOVANOVICH, AND T. A. POND, *Washington University.*—About 1 mc of Ne-19 is maintained continuously in a 50 cm³ chamber between the poles of an electromagnet. The chamber is viewed from either end through the pole tips (2-in. of saturated Armco) by two 1-in. D×1½-in. NaI scintillation spectrometers biased to record only $\gamma$-rays of greater than a certain energy, $E_0$. This bias is usually set above 0.51 Mev so that only the $\gamma$-ray emitted into the hemisphere around the momentum of a positron annihilating in flight can be recorded. If the positron is longitudinally polarized, this $\gamma$-ray is circularly polarized: for positive positron helicity, LCP.[1] Because of the electron spin dependence of the Compton scattering of such $\gamma$-rays in the poles, the two counting rates show an asymmetry which reverses when the direction of magnetization is reversed. This asymmetry is $(1.60 \pm 0.18)\%$ for $E_0 = 1.3$ Mev, $(1.25 \pm 0.19)\%$ for $E_0 = 1.0$ Mev, $(0.86 \pm 0.15)\%$ for $E_0 = 0.75$ Mev, and $(0.11 \pm 0.05)\%$ for $E_0 = 0.35$ Mev. The asymmetries to be expected from full positron polarization, $+v/c$, have been calculated from the differential cross sections for the production of RCP and LCP $\gamma$-rays from positrons which annihilate isotropically. The agreement with the observed asymmetries is excellent.

* Supported by the Research Corporation and the U. S. Air Force Office of Scientific Research.

[1] L. A. Page, Phys. Rev. 106, 394 (1957); Deutsch, Gittelman, Bauer, Grodzins, and Sunyar, Phys. Rev. 107, 1733 (1957); Boehm, Novey, Barnes, and Stech, Phys. Rev. 107, 1497 (1957).

**B6. Z Dependence of Circular Polarization of External Bremsstrahlung.** S. GALSTER AND H. SCHOPPER *University of Mainz.*—The circular polarization of external bremsstrahlung excited by beta particles of $Sr^{90}+Y^{90}$ which are decelerated in various absorbers was measured as a function of $Z$ for different photon energies. The forward scattering from magnetized iron was used as an analyzer. Within the experimental errors, no $Z$ dependence was found for all photon energies. From this it may be concluded that electron scattering and other secondary effects in the thick target do not influence the polarization appreciably. Hence, the measured polarization as a function of quantum energy can be compared with calculations for thin targets taking into account the energy distribution of the $\beta$ particles and the emission probability of bremsstrahlung. The agreement is very good, whereas the curve calculated for monoenergetic electrons is at variance with the experimental results.

**B7. Circular Polarization of Internal Bremsstrahlung Emitted in the $K$ Capture of $A^{37}$.** G. HARTWIG AND H. SCHOPPER, *University of Mainz.*—The inner bremsstrahlung emitted in $K$ capture is expected to be 100% circularly polarized for all photon energies if parity violation is maximum. Therefore the measurement of this polarization is especially useful for the exact determination of the degree of parity violation. However, an experimental difficulty is the low intensity of this bremsstrahlung (about 1 photon/$10^4$ capture processes). The circular polarization for the $K$ capture of $A^{37}$ was measured using the forward scattering from magnetized iron as an analyzer. For all photon energies above 200 kev the polarization is complete. For the lowest discriminator setting ($\sim$120 kev) there is some contribution from $p$-electron capture giving unpolarized bremsstrahlung. Omitting this measurement, an average value of the polarization $P = 1.03 \pm 0.04$ is obtained. The helicity of this bremsstrahlung is positive in contrast to that for inner bremsstrahlung accompanying $\beta^-$-decay which is negative.

**B8. On the Polarization of Low Energy β-Particles.** J. F. TURNER, G. A. GARD, AND P. E. CAVANAGH, *Atomic Energy Research Establishment, Harwell.*—Observations of the energy dependence of the polarization of $\beta$-particles in the energy range 55 to 160 kev reported at the Rehovoth Conference[1] for $Co^{60}$ $\beta$-particles, have been extended to $Au^{198}$ and $Au^{199}$. A departure from a $v/c$ dependence of polarization is observed, with experimental values $(0.643 \pm 0.030)$ $v/c$ at 56 kev, $(0.884 \pm 0.040)$ $v/c$ at 97 kev, $(0.865 \pm 0.056)$ $v/c$ at 128 kev, all these values based on the assumption of a $v/c$ polarization of $Co^{60}$ $\beta$-particles at 128 kev. The Mott scattering method is employed, using crossed electric and magnetic field to reorient the electron spin. Uncertainties in the Mott scattering asymmetry as a function of energy are avoided by an arrangement whereby the energy of electrons striking the scatterer is held constant, even though the selected $\beta$-ray energy is varied. The interpretation of the result as such requires that the $\beta$-interaction is not pure $V$-$A$. It is possible to fit the form of the departure from $v/c$ dependence with expressions derived by Berestetsky *et al.*[2] for a general $STVA$ interaction. In this the dominant term appears to be a time reversal invariance violating term, though other terms are present due to the first forbidden nature of the transition. If the Au 56-kev result is ignored it would be possible to fit all the remaining data with a strict $v/c$ dependence.

[1] P. E. Cavanagh, Proc. Rehovoth Conf. Nuclear Structure, p. 394.
[2] Berestetsky, Ioffe, Rudik, and Ter-Martirosyan, Phys. Rev. 111, 522 (1958).

**C2. Electron-Neutrino Angular Correlations in the Beta-Decays of $He^6$, $Ne^{19}$, $Ne^{23}$, and $A^{35}$.*** W. B. HERRMANNFELDT,† R. L. BURMAN, P. STÄHELIN,‡ AND J. S. ALLEN, *University of Illinois,* AND T. H. BRAID, *Argonne National Laboratory.*—The angular correlation coefficients in the allowed beta-decay of $He^6$, $Ne^{19}$, $Ne^{23}$, and $A^{35}$ have been experimentally determined by measurements of the energy spectra of the recoil ions. The form of the beta-decay interaction has been deduced from these measurements. The values of the angular correlation coefficients and the corresponding interaction forms observed in these experiments are listed in Table I. It is

TABLE I

| Isotope | Selection rules | Correlation coefficient | Interaction forms |
|---|---|---|---|
| $He^6$ | G-T | $-0.39\pm0.05$ | A |
| $Ne^{19}$ | mixed | $0.00\pm0.08$ | ST or VA |
| $Ne^{23}$ | G-T | $-0.37\pm0.04$ | A |
| $A^{35}$ | mostly F | $+0.97\pm0.14$ | VT or VA |

* Work performed under the auspices of the U. S. Atomic Energy Commission and also supported in part by the Office of Naval Research.
† Now at Los Alamos Scientific Laboratory, Los Alamos, New Mexico.
‡ Now at the Swiss Institute of Technology, Zurich, Switzerland.

apparent from Table I that the experimental results are consistent if we assume that the dominant beta-decay interaction is VA.

**C3. Recoil Momentum Spectra for the β-Decay of $He^6$.** F. PLEASONTON, C. H. JOHNSON, AND A. H. SNELL, *Oak Ridge National Laboratory.*—The momentum spectrum of single charged $Li^6$ recoils following the $\beta$-decay of $He^6$ is being studied with the spectrometer which was used for an earlier investigation[1] of $A^{37}$. $He^6$ is generated in BeO powder by the $Be^9(n,\alpha)He^6$ reaction at the Oak Ridge Research Reactor. Water vapor carries the $He^6$ to the spectrometer, where the $He^6$ is left to decay in a field-free conical source volume. The spectrometer uses magnetic and electrostatic deflectors, in series, thus eliminating any simultaneous observation of singly and doubly charged $Li^6$ ions. Three stages of differential pumping enable us to count with a signal to background ratio of four at the peak of the charge one spectrum. The upper 60% of this momentum spectrum has been observed and agrees well in shape with the theoretical curve for a pure axial-vector interaction. The charge two spectrum exhibits the same shape within the statistical uncertainties ($\pm5\%$). Comparison of intensities at 1000 ev yields an abundance ratio charge 2/charge $(1+2)=9.5\pm0.5\%$ (theory: $10.5\pm1.5\%$[2]). The observed end point of the recoil spectrum corresponds to a $\beta$-decay energy of $3.52\pm0.02$ Mev.

[1] A. H. Snell and F. Pleasonton, Phys. Rev. 100, 1396 (1955).
[2] A. Winther, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. 27, No. 2 (1952).

**C4. Inner Bremsstrahlung (IB)—Nuclear Recoil Angular Correlation in Beta-Decay.*** S. D. BLOOM AND J. L. URETSKY, *University of California, Livermore and Berkeley.*—The possibility of measuring the angular correlation between IB and nuclear recoils has been investigated with special attention to the unique super-allowed $K$-capture decay of $Be^7$. The theoretical result predicts a strong dependence on the absolute value of the ratio $|C_V|/|C_A|$, if, say, only these two coupling constants are involved. Only the ratio of absolute values of coupling constants can be measured in this kind of an experiment, as it is basically equivalent to any electron-neutrino angular correlation experiment, where results are independent of whether parity breaks down. The angular correlation between IB and nuclear recoil can be expected to be a non-zero effect in general, but $Be^7$ is an especially interesting case for these reasons: (1) Beryllium-7 decay involves both Fermi and Gamow-Teller matrix elements, so that, in general, the relative ratio of all coupling constants (times the matrix element) can be investigated. (2) Because of the simple shell structure of $Be^7$ and its super-allowedness, theoretical matrix element calculations can be made with some reliability. (3) Experimentally, nuclear recoil detection techniques for $Be^7$ are well developed. Possible experimental arrangements will be discussed, and, also, correlation formulas for the general case as well as $Be^7$ in particular will be given.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

**C5. O− → O+ Beta Transition in $Pr^{144}$.*** FRED T. PORTER AND PAUL P. DAY, *Argonne National Laboratory.*—The Argonne double-lens spectrometer has been used to observe the beta-transitions of $Pr^{144}$. The shape of the 1.20% abundant, 2.29-Mev beta-transition to the first excited state (2+) of the even-even daughter $Nd^{144}$ was measured in coincidence with the 702-kev gamma ray. The shape is the unique one ($\Delta I=2$, yes). The 0.97% abundant 807-kev group, measured in coincidence with the 1.48- and 2.18-Mev gammas, has the allowed shape. These shapes, along with the $\beta$-$\gamma$ directional correlations[1] and the $\gamma$-$\gamma$ directional correlations[1] point strongly to an O− assignment for $Pr^{144}$. This makes the 98% abundant 2.996-Mev ground state beta-transition an O− to O+ case. Its shape, derived from the total spectrum after small and insensitive subtraction of the inner groups, measures the relative contributions of $\int\gamma_5$ and $\int\sigma\cdot r$, axial vector matrix elements in this transition. Our results show the ground state transition to be close to the allowed shape but with relatively fewer electrons at lower energies. A weighted least squares criterion gives $\lambda=i\int\gamma_5/\int\sigma\cdot r=5\pm2$. These results are in agreement with Graham *et al.*[1] but in disagreement with the experimental shape of Laubitz.[2] Attempts to fit anything close to the allowed shape with $T$-$P$ mixtures have met with little success while the presently accepted $V$-$A$ interaction meets the challenge quite easily.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Graham, Geiger, and Eastwood, Can. J. Phys., 36, 1084 (1958).
[2] M. J. Laubitz, Proc. Phys. Soc. (London) A69, 789 (1956).

**D2. Time Reversal Invariance in the Neutron Decay.** M. A. CLARK AND J. M. ROBSON, *Atomic Energy of Canada Limited*, AND R. NATHANS, *Brookhaven National Laboratory.*—The Chalk River experiment[1] to detect an effect of the form[2] $D\cdot(\mathbf{J}/|J|)\cdot(P_e\times P_\nu)/E_eE_\nu$ in the electron-neutrino angular correlation in polarized neutron decay has been continued. Data taken through August 1958 yield a value $D=-0.09\pm0.20$. Under the assumption of a pure $V\pm A$ interaction (or pure $S\pm T$ interaction) this result corresponds to a phase angle between Fermi and Gamow-Teller parts of the interequal action to $10°\pm25°$ measured with respect to either $0°$ or $180°$.

[1] Clark, Robson, and Nathans, Phys. Rev. Letters 1, 100 (1958).
[2] Jackson, Treiman, and Wyld, Phys. Rev. 106, 517 (1957).

**D3. Angular Correlation Experiments and Time-Reversal Invariance of the Beta Interaction.*** P. C. SIMMS AND R. M. STEFFEN, *Purdue University.*—Following a suggestion by Curtis and Lewis, an attempt was made to obtain information on time-reversal invariance by measuring the electron-polarization-gamma-directional correlation in the first forbidden beta-decay of $Au^{198}$. The transverse polarization of the beta particles was determined by observing the asymmetry in a Mott scattering process. The experimental result for an average electron momentum of $p=1.7$ is

$$W(p_0,k,n)=1+(0.0088\pm0.0004)[3(p_0\cdot k)^2-1]-(0.026\pm0.012)(p_0\cdot k)(n\cdot k)-(0.006\pm0.026)(n\times p_0\cdot k)(p_0\cdot k). \quad (1)$$

$p_0$ is a unit vector in the direction of the momentum $p$ of the beta particle, $n$ and $k$ are unit vectors in the direction of the electron spin ($n$ orthogonal to $p$), and the gamma-ray photon, respectively. Iben and Kotani have recently shown that only a careful measurement of the energy dependence of the coefficient of the last term of Eq. (1) could give information on time-reversal invariance. In view of the smallness of the polarization effects such an investigation seems to be beyond the possibilities of present experimental techniques. The fact that the experiment establishes a different sign for the coefficient of the third term in Eq. (1) as compared to the sign

of the second one gives evidence of the predominance of the $V$-$A$ coupling in beta decay.

* Supported by the U. S. Atomic Energy Commission.

**E2. β Spectrum of RaE and Time Reversal.** JUN-ICHI FUJITA, *Nihon University, Tokyo,* MASAMI YAMADA, *National Research Council,* AND ZYUN-ITIRO MATUMOTO AND SEITARO NAKAMURA, *University of Tokyo.*—The $\beta$ spectrum of RaE was analyzed in order to get information about the interference term between the Fermi and the Gamow-Teller components. Let us specify the Fermi and the Gamow-Teller components as vector ($V$) and axial-vector ($A$) types respectively. We also assume the time reversal invariance of strong interactions. Then, the interference term is proportional to

$$\cos\theta_{VA} = Re(C_V^* C_A + C_V'^* C_A')/[(|C_V|^2+|C_V'|^2)(|C_A|^2+|C_A'|^2)]^{\frac{1}{2}},$$

where $C_i$ and $C_i'$ are parity conserving and nonconserving coupling constants respectively. Taking into account all the effects due to the finiteness of the nuclear size, we obtain the lower limit of the interference term as $|\cos\theta_{VA}|>0.967$, i.e., $|\theta_{VA}|<15°$, or $|\theta_{VA}-180°|<15°$. These results that the interference is almost maximum suggest the validity of time reversal invariance in $\beta$ decay.

**E3. Higher Order Corrections to the Allowed Beta Decay.** M. MORITA, *Columbia University.*—Theoretical works on the shape of the allowed beta spectrum[1] and the directional correlations of allowed beta ray and gamma or alpha rays[2] have been reinvestigated with an assumption of $VA$. We take into account the Coulomb field due to the daughter nucleus, the finite de Broglie wavelength effect, and the contribution of the second forbidden matrix elements, $\int r^2$, $\int \boldsymbol{\alpha}\cdot\mathbf{r}$, $\int \boldsymbol{\sigma} r^2$, $\int (\boldsymbol{\sigma}\cdot\mathbf{r})\mathbf{r}$, $\int \gamma_5\boldsymbol{\gamma}$, and $\int \boldsymbol{\alpha}\times\mathbf{r}$, simultaneously. Relations between coordinate type and momentum type matrix elements are given in the nonrelativistic approximation. The results indicate that the shape of the beta spectrum will be somewhat different from that given by Gell-Mann,[3] who has considered only the contribution of the momentum type matrix elements in the Gamow-Teller allowed transitions. The ratio of the correction factors for the beta spectrum of $B^{12}$ and $N^{12}$ varies over the whole spectrum about 12%. This is the sum of the contributions of 16% from $\int \boldsymbol{\alpha}\times\mathbf{r}$ term (assuming $\int \boldsymbol{\alpha}\times\mathbf{r}/\int \boldsymbol{\sigma} = (\mu_P-\mu_N)M^{-1}$, $-3$% from the finite de Broglie wave length effect, and $-1$% from the other matrix elements. If we use $\int \boldsymbol{\alpha}\times\mathbf{r}/\int \boldsymbol{\sigma} = M^{-1}$ given in the nonrelativistic approximation, both correction factors of $B^{12}$ and $N^{12}$ are almost constant in the whole energy region.

[1] J. Fujita and M. Yamada, Progr. Theoret. Phys. (Japan) **10**, 518 (1953).
[2] M. Morita and M. Yamada, Progr. Theoret. Phys. (Japan) **13**, 114 (1955).
[3] M. Gell-Mann, Phys. Rev. **111**, 362 (1958).

**E4. Radiation Correction to the Allowed β-Spectrum Shape—Application to the Spectra of $N^{12}$ and $C^{12}$.*** ARTHUR SCHWARZSCHILD, *Brookhaven National Laboratory and Columbia University.*—Corrections to the allowed spectrum shape due to inner bremsstrahlung emission has been calculated. The inner bremsstrahlung process is characterized by the probability function $\Phi(\epsilon_0,k)$ of Knipp and Uhlenbeck. Integrals of this function over the allowed $\beta$-spectrum yield the correction factor $C_R(\epsilon,\epsilon_0)$ tabulated below. This effect has not been detected in previously measured spectra since the shape correction is equivalent to a small change in endpoint. However, for the recently suggested comparison of the spectra of $C^{12}$ and $N^{12}$ the radiation correction varies as much as the "Gell-Mann term" in the region between 9 and 13 Mev. It is therefore suggested that a calculation of radiative corrections including virtual photon effects is necessary.

| $\epsilon-1$ \ $\epsilon_0$ (mc²) | 2 | 4 | 10 | 20 | 40 |
|---|---|---|---|---|---|
| 0.1 | −0.002 | −0.005 | −0.013 | −0.026 | −0.054 |
| 0.2 | −0.001 | −0.003 | −0.009 | −0.017 | −0.026 |
| 0.4 | 0.000 | 0.001 | 0.002 | 0.004 | 0.005 |
| 0.8 | 0.003 | 0.008 | 0.014 | 0.023 | 0.036 |
| 0.94 | 0.007 | 0.018 | 0.030 | 0.046 | 0.062 |
| 0.96 | 0.008 | 0.020 | 0.035 | 0.053 | 0.070 |
| 0.98 | 0.009 | 0.023 | 0.042 | 0.067 | 0.102 |

* Work performed in part under the auspices of the United States Atomic Energy Commission.

**E5. The Ratio of the Gamow-Teller and Fermi Coupling Constants.*** O. C. KISTNER AND B. M. RUSTAD, *Columbia University* AND *Brookhaven National Laboratory.*—The evaluation of the ratio of the squares of the Gamow-Teller and Fermi coupling constants, $C_{GT}^2/C_F^2$, from the $ft$ values of the mirror transitions between doubly closed shell + one nucleon, nuclear configurations together with those of the 0-0 spin transitions has been reconsidered on the basis of the latest experimental information. When the Gamow-Teller matrix elements, $|\int \boldsymbol{\sigma}|^2$, are calculated according to the method[1] of magnetic moment interpolation between the Schmidt limits, the $ft$ values of $H^3$, $O^{15}$, $F^{17}$, and $Ca^{39}$ are found to be consistent, within the experimental errors, with a unique value of $C_{GT}^2/C_F^2$. The predictions of $|\int \boldsymbol{\sigma}|^2$ for $O^{15}$ and $F^{17}$ are considered the most reliable because the magnetic moments for these cases are very close to those predicted by the single particle model, and the $ft$ values of these transitions were used to obtain a value of $1.16\pm0.05$ for $C_{GT}^2/C_F^2$. The $ft$ of the neutron, however, based on the recent half-life measurements[2] of $11.7\pm0.3$ min leads to a ratio of $1.42\pm0.08$. To bring these results into agreement, the predictions of $|\int \boldsymbol{\sigma}|^2$ for $H^3$, $O^{15}$, $F^{17}$, and $Ca^{39}$ would all have to be reduced by approximately 20%.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] A. Winther and O. Kofoed-Hansen, Dan. Mat-Fys. Medd. **27**, (14) (1953).
[2] Sosnovskij, *et al.*, to be published (Reported at the High Energy Conference, Geneva, July, 1958).

**E6. Polarization of Conversion Electrons following Beta Decay.** RICHARD L. BECKER AND M. E. ROSE, *Oak Ridge National Laboratory.*—Because of the non-conservation of parity and charge conjugation, beta decay provides a means of obtaining polarized excited nuclei. A previous calculation[1] of the authors has shown that conversion electrons following the beta decay should exhibit not only longitudinal but also appreciable transverse polarization (e.g., about 20–30%) in the plane of the beta and the conversion electron. It was suggested that the experimental measurement of transverse conversion polarization in coincidence with the beta might provide some advantages (over longitudinal $\beta$-polarization or circular $\gamma$-polarization) for testing the validity of the two-component theory. Also, the conversion polarization provides an alternative means of obtaining the multiple mixture parameter. The present work extends the previous results, which were limited to pure multipole conversion following allowed beta decay, to include mixed multipole conversion following allowed and pure multipole conversion following unique first forbidden transitions. In addition, extensive numerical results have been obtained for $K$ conversion. From the curves available, one can easily compute the conversion polarization (longitudinal as well as transverse) as a function of beta and conversion energy, angle between beta and conversion electron, multipole order and mixture, and nuclear spins.

[1] M. E. Rose and Richard L. Becker, Phys. Rev. Letters **1**, 116 (1958).

**E7. Dirac Theory of Spin 1/2 Particles and its Relativistic Limit.** S. K. BOSE and A. GAMBA, *University of Rochester,* AND E. C. G. SUDARSHAN, *Harvard University.*—A representa-

tion which exhibits the properties of a Dirac particle in the extreme relativistic limit is discussed, which is complementary to the Foldy-Wouthuysen transformation.[1] The separation into positive and negative energy states arises in a natural manner; and physical observables should be identified with "even" operators. The natural position operator $\mathbf{x}_+$ in this representation is distinct from the familiar Newton-Wigner operator[2] and is defined for two-component massless neutrinos also. The operator $\mathbf{x}_+ \times \mathbf{p}$ represents the transverse part of the *total* angular momentum. The operator $\mathbf{x}_+$ has the proper commutation relations with $\mathbf{p}$ and its analogue exists for the case of higher spin massless particles, in particular for the photon. Finally, the electromagnetic properties of relativistic electrons are exhibited more simply in our representation.

[1] L. L. Foldy and S. A. Wouthuysen, Phys. Rev. **78**, 29 (1950).
[2] T. D. Newton and E. P. Wigner, Revs. Modern Phys. **21**, 400 (1949).

**E8. Are the Two-Component Weyl-Pauli Neutrino Equations Invariant Under Parity Transformation (P) or Under Combined Inversion (CP) Only?** EUGENE GUTH, *Oak Ridge National Laboratory.*—Pauli, in his masterful 1933 article on the general principles of wave mechanics, derived the two-component neutrino equation only to dismiss it with the remark: "These wave equations are not invariant under reflection and therefore not applicable to physical reality." In a recent reprinted version [*Handbuch der Physik*, (Springer-Verlag, Berlin), Vol. V, Part 1] this famous error has been rectified by the omission of the last eight words. Unfortunately, Pauli's statement as it stands now with the omission is still misleading. He means (but does not say) that the equations referred to are not invariant under reflection, if only *linear* transformations of the wave functions are admitted. Serpe [Physica (1952); Nuclear Phys. (1957)], McLennan [Phys. Rev. (1957)], and Case [Phys. Rev. (1957)] give the misleading impression that—contrary to Pauli's statement—the Weyl-Pauli equations are invariant under reflection. This is true provided one admits *nonlinear* transformations ($\psi \rightarrow \sigma_2 \psi^*$) of the wave functions, but *reflection corresponds here to combined inversion (CP) rather than to parity transformation (P).* Even in $c$-number theory it is not sufficient *in this case* to prove the invariance of the wave equation only, but the commutation relation $qp - pq = i$ must also be invariant. This is true for Wigner's time reversal ($T$) [$p \rightarrow -p$; $i \rightarrow -i$] and $CP$[$p \rightarrow -p$, $q \rightarrow -q$], but *not* for $P$[$p \rightarrow -p$; $q \rightarrow -q$; $i \rightarrow -i$].

**G1. Radiative Corrections to Fermi Interactions.** TOICHIRO KINOSHITA, *Cornell University* AND ALBERTO SIRLIN, *Columbia University.*—The study of the lowest order radiative corrections to the decay of polarized muons has been corrected for a mistake in the treatment of the low energy quanta, recently pointed out by S. M. Berman. It is found that this further correction increases the $\rho$ value by about 1%, the over-all effect of the radiative corrections on the $\rho$ value being now of the order of 5.6% in the spectral region $0 \leq p_e/p_{e\max} \leq 0.95$. The effect of this further correction on the parameters $\zeta, \xi$ and the momentum dependence of the asymmetry is not significant. As a point of theoretical interest, it is found that while the differential spectrum contains terms of the form $\alpha \ln(m_\mu/m_e)$, these terms vanish after integration over all electron momenta. Thus, the corrections to the lifetime are finite in the limit $m_e \rightarrow 0$. Exactly the same behavior is established in the case of the neutron decay. The effect of the radiative corrections on the spectral shape and lifetime of the neutron decay will be discussed.

**G2. Two-Neutrino Hypothesis.** S. A. BLUDMAN, *University of California, Berkeley.*—A description of leptons is discussed in which, neglecting mass differences, $e^-\nu e^+$ is a charge triplet which is, like the $\pi$ triplet, self charge-conjugate. This formalism automatically makes the $\nu$ a Majorana or two-component spinor. When lepton conservation is assumed, $\nu$ must be massless and only $V$ and $A$ forms of $e$-$\nu$ coupling are possible. The possibility is suggested that the $\mu$ is a member of a charge doublet along with a neutral particle $\lambda$, that is different from $\nu$. Since a doublet cannot be its own charge conjugate, $\mu$ and $\lambda$ are not in general massless, even in the non-electric approximation presented here. The charge structure of the leptons $\lambda\mu$ and $e^-\nu e^+$ is then the same as that of the mesons $K^0K^+$ and $\pi^-\pi^0\pi^+$, but essentially different from that of the baryons $\eta$ and $\Sigma$, for which particle and antiparticle are distinguished by the baryon conservation law. Whereas the $\beta$ decay evidence shows $m_\nu \leqslant 0.0004$, the $\pi \rightarrow \mu + \lambda$ and $\mu \rightarrow \lambda + e + \nu$ end points allow a much larger value, $m_\lambda \leqslant 10 m_e$ for the $\lambda$ mass. For $m_\lambda \sim 10 m_e$, the expected $\rho$ value is decreased by $\sim 0.03$, depending on how $\rho$ is extracted from the experiment. Independently of the $\lambda$ mass, $\mu \rightarrow e + \gamma$ is forbidden absolutely.

**G3. Depolarization Processes for Negative Mu Mesons.** M. E. ROSE, *Oak Ridge National Laboratory.*—The small decay asymmetry observed in $\mu^- \rightarrow e^-$ can be understood largely in terms of spin decoupling and hyperfine interaction in radiative (*El*) transitions to the $1s_{\frac{1}{2}}$ ground state once a stable orbit is formed by Auger capture (electron ejection). The initial orbits thus formed are characterized by large principal quantum number $n$ and by a broad distribution in $l$. Neglecting ordinary Auger transitions, valid for $H$, the radiative spin decoupling occurs largely in spin flip ($j = l - \frac{1}{2} \rightarrow j' = l' + \frac{1}{2}, l = l' + 1$) transitions which are most probable for small quantum numbers. Thus, most of the depolarization occurs in $2p_{\frac{1}{2}} \rightarrow 1s_{\frac{1}{2}}, 3d_{\frac{1}{2}} \rightarrow 2p_{\frac{1}{2}}$ transitions. Depolarization by hyperfine coupling is most important in $j = \frac{1}{2}$ states. Averaging over-all possible cascades between circular and nearly circular orbits gives a polarization of 50% of initial value for no $hf$ coupling and 16% with $hf$ coupling. These values represent upper limits since depolarization in Auger capture and by Auger collisions is neglected. In addition collision induced transitions of the $\mu$-mesic atom in the ground state from $F=1$ to $F=0$ result in complete depolarization. The circular polarization of x-rays emitted is of the same order of magnitude as the meson polarization.

**G4. Hyperfine Structure of $He^4 - \mu^- e^-$.*** V. W. HUGHES,† *Brookhaven National Laboratory and Yale University* AND S. PENMAN, *Columbia University.*—The availability of polarized muons and of a method for their detection may make possible a measurement of the hyperfine structure of the ground state of the system consisting of a $He^4$ nucleus, a negative muon, and an electron; hence it is useful to consider the theoretical value of this hfs splitting. The $\mu^-$ meson will be bound closely to the $He^4$ nucleus as in a mu-mesic atom, and the electronic wavefunction will be approximately hydrogenic. Hence in the lowest approximation the hfs splitting, $\Delta W$, (which is inverted) is given by the Fermi formula and has the same value as for muonium. The principal corrections to this approximation arise from the finite size of the $He^4$-$\mu^-$ atom, the reduced mass correction, and the anomalous magnetic moments of electron and muon. The expression:

$$\Delta W = (\Delta W)_F (1 - 3m_e/2m_\mu)(1 + m_e/m_{He})^{-3}(1 + \alpha/2\pi)^2 = (4492 \pm 4)\ \text{Mc/sec}$$

gives these correction factors in the order listed. Higher order corrections arising from radiative processes, a more accurate treatment of muon and electron wavefunctions, the finite size of the $He^4$ nucleus, and recoil are omitted to the accuracy quoted.

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† Presently on leave at Columbia University.

**G5. Theoretical Rate for $\mu^- + C^{12} \rightarrow B^{12} + \nu$.** L. WOLFENSTEIN, *Carnegie Institute of Technology.*—The possibility of improved measurements on the capture process $\mu^- + C^{12} \rightarrow B^{12} + \nu$ makes it of interest to review the possible use of this measurement to check the validity of the universal $V$-$A$ interaction hypothesis. The predicted ratio $R$ of the capture rate to the ground state of $B^{12}$ to the muon decay rate is $1.2 \pm 0.3\%$ if the nuclear matrix element is deduced[1] from the beta-decay rate of $B^{12}$ and the effective pseudoscalar coupling[2] deduced from the $\pi \rightarrow \mu + \nu$ rate is included. The theoretical error (of somewhat arbitrary magnitude) is chiefly due to the uncertainty in the nuclear matrix element and the possible contributions of second forbidden transitions, particularly those which may be called "relativistic transitions of order 1." If one assumes that the vector interaction is represented by a "conserved current," there results one large calculable second forbidden contribution[3] which raises $R$ to $1.6 \pm 0.4\%$.

[1] T. N. K. Godfrey, Thesis, Princeton University (1954).
[2] L. Wolfenstein, Nuovo cimento X, 8, 882 (1958); M. Goldberger and S. Treiman, Phys. Rev. 111, 354 (1958).
[3] M. Gell-Mann, Phys. Rev. 111, 362 (1958).

**G6. Absorption of Mu Mesons by Carbon —I.*** T. H. FIELDS, R. L. MCILWAIN, AND J. G. FETKOVICH, *Carnegie Institute of Technology.*—A negative muon beam from the Carnegie Tech synchrocyclotron was stopped in a six-in. propane bubble chamber. Since the hydrogen does not form mu-mesic atoms in the presence of carbon, the pictures yield information on the interaction of stopped muons with carbon. Approximately 1000 stopped muons were studied, and $(9.0 \pm 0.9)\%$ of these did not give rise to a $\mu$-$e$ decay electron. This yields an absorption rate of $(0.45 \pm 0.045) \times 10^6$ sec$^{-1}$, in good agreement with the value $(0.43 \pm 0.10) \times 10^6$ sec$^{-1}$ obtained from lifetime measurements,[1] and with the theoretical value of $0.45 \times 10^6$ sec$^{-1}$ predicted by Primakoff.[2] In addition, the muon absorptions yielding visible prongs are being studied.

* This work supported in part by the U. S. Atomic Energy Commission.
[1] Sens, Swanson, Telegdi, and Yovanovitch, Phys. Rev. 107, 1464 (1957).
[2] H. Primakoff, *Proceedings of the Fifth Annual Rochester Conference in High Energy Physics* (Interscience Publishers, Inc., New York, 1955), p. 174.

**G7. Absorption of Mu Mesons by Carbon—II.*** J. G. FETKOVICH, T. H. FIELDS, and R. L. MCILWAIN, *Carnegie Institute of Technology.*—The beam and apparatus used in this experiment were identical with that described in the previous abstract except that a double-exposure photography technique was used to gain some time discrimination. The chamber was kept sensitive for about 20 msec after the beam pulse It was photographed at 1.5 msec and again at 15 msec after the beam pulse, using moving film to separate the two images. The purpose of the measurement was to determine the number of absorbed muons which led to a bound state of $B^{12}$. The boron was detected by the presence of its decay electron in the late picture, while no decay electron emanated from the mu ending in the early picture. Based on 47 observed $B^{12}$ decays, the ratio of the number of muons which led to a bound state of $B^{12}$ to the number which underwent $\mu$-$e$ decay is $(1.55 \pm 0.23)\%$. This result is in agreement with that of Godfrey[1]; however, the possibility that a significant fraction of the $B^{12}$ is formed in an excited state, together with theoretical uncertainties, make the determination of the mu absorption $G$-$T$ coupling constant uncertain.

* This work supported in part by the U. S. Atomic Energy Commission.
[1] T. Godfrey, Princeton University, thesis, 1954 (unpublished).

**G8. $B^{12}$ Formation by Absorption of $\mu^-$ Mesons in $C^{12}$.*** W. LOVE, S. MARDER, I. NADELHAFT, R. SIEGEL, AND A. E. TAYLOR,† *Carnegie Institute of Technology.*—A scintillation counter array was used to detect delayed electrons emitted from a one-in. thick polystyrene (CH) stopping counter placed in an external meson beam of the Carnegie cyclotron. The machine was on for a period of 40 millisec, followed by an off period of 120 msec during which particles from the stopping counter emitted forwards or backwards relative to the beam direction were counted, and their time structure analyzed. When an amount of carbon absorber corresponding to the $\mu^-$ range was placed ahead of the counter array, the 20 msec activity of $B^{12}$ was observed, superposed on a small random background. Various tests to insure that the effect was due to capture of $\mu^-$ mesons will be described. Preliminary analysis indicates the rate of $B^{12}$ formation to be about one percent of the rate of $\mu^-$ mesons stopping in the counter.

* Supported by the U. S. Atomic Energy Commission.
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**GA3. Electron Decay of the Positive Pion.*** H. L. ANDERSON, T. FUJII, R. H. MILLER, AND L. TAU, *University of Chicago.*—The remarkable success of the $A$-$V$ theory in accounting correctly for many phenomena involving the weak interaction has raised doubt about our previous failure to observe the electronic decay of the pion.[1] Accordingly, we decided to make a new attempt, and this effort was accelerated when we learned of the successful observations of this process by the CERN group[2] and by Steinberger, *et al.*[3] We used the same spectrometer, modified to accommodate three detectors, allowing simultaneous observation in three energy channels. The same electronic circuits were used but arranged to allow a more detailed observation of each event by photographing the screen of a traveling wave oscillograph. Limiting our selection of $\pi$-$e$ events in the time interval greater than 22 m$\mu$sec and less than 150 m$\mu$sec, we found 94 events out of a total 585 in the neighborhood of 67 Mev which we identify as $\pi$-$e$ events. Our preliminary analysis gives an energy within 0.5 Mev of 69.8 Mev, a mean life of 25.1 m$\mu$sec, and a branching ratio of $(1.1 \pm 0.3) \times 10^{-4}$.

* This research supported by a joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] H. L. Anderson and C. M. G. Lattes, Nuovo cimento 6, 1356 (1957).
[2] Fazzini, Fidecaro, Merrison, Paul, and Tollestrup, Phys. Rev. Letters 1, 247 (1958).
[3] Impeduglia, Plano, Prodell, Samios, Schwartz, and Steinberger, Phys. Rev. Letters 1, 249 (1958).

**H2. Electric Dipole Moment of the Muon.*** D. BERLEY, R. L. GARWIN,† G. Gidal, and L. M. LEDERMAN, *Columbia University.*—A search is being made for an electric dipole in the muon with an eventual sensitivity of the order of 0.2% of a natural moment: $e$ times the muon Compton wavelength.[1] Longitudinally polarized $\mu$ mesons pass through a region of transverse electric field. The presence of an electric dipole moment would result in a torque which would cause the spin to precess away from the longitudinal direction. In the present experiment the electric field is that created in the rest system of the muon by its motion in a magnetic field. Transverse components of the spin are measured by using the $\mu$-decay electron asymmetry as the polarization detector. From the work performed to date, the value of the electric dipole moment is found to be $0.006 \pm 0.005$ times the natural unit and this is consistent with a vanishing moment. Other aspects of the electric dipole moments of charged particles will be discussed.

* This work is supported by the U. S. Atomic Energy Commission and the Office of Naval Research.
† Also at International Business Machines Watson Laboratory, Columbia University.
[1] Berley, Garwin, Gidal, and Lederman, Phys. Rev. Letters 1, 144 (1958).

**H3. Longitudinal Polarization of the Electrons from the Decay of Unpolarized Positive and Negative Muons.** G. CULLIGAN, S. G. F. FRANK, AND J. R. HOLT, *University of Liverpool.*—The polarization of electrons from the decay of unpolarized positive and negative muons has been detected by the method of transmission of bremsstrahlung through magnetized iron. It is shown that the positrons have positive

helicity and the negatrons negative helicity, thus providing a clear demonstration of violation of invariance under charge conjugation. It follows on the basis of the two component neutrino theory that the neutrino associated with the decay of the pion has negative helicity and the antineutrino positive helicity. The agreement of this with recent results for the neutrino in $\beta$-decay lends support to this theory and to the law of conservation of leptons.

**H4. $\beta$ Decay of the $\mu^+$ Meson: Momentum Spectrum and Asymmetry.** R. J. PLANO AND A. LECOURTOIS, *Columbia University.*—The decay of the $\mu^+$ meson is being studied utilizing a 12-in. diam×6-in. deep liquid hydrogen bubble chamber in a magnetic field of 8800 gauss. In a typical picture 10–15 incident $\pi^+$ mesons stop and undergo the usual $\pi$-$\mu$-$e$ decay. An event is selected for measurement if a quick test indicates the $\mu$ velocity has a large component along the magnetic field. The $\mu$ direction and the positron momentum are then measured to determine the asymmetry in $\mu^+$ decay as a function of the positron momentum and also to determine the momentum spectrum of the positron from $\mu^+$ decay. A positron is utilized in the momentum spectrum if it satisfies the criteria: 1. Dip angle $<45°$ 2. Potential length $>7$ cm. The momenta are measured with an average measurement error of 1% and an average multiple scattering uncertainty of 4%. We have attempted to correct for the energy loss of the electron, the effective magnetic field along each electron's path, and the overall magnification sufficiently well to reduce the systematic errors below 0.2%, which corresponds to an error of 0.01 in $\rho$. A preliminary analysis of the asymmetry data based on 4094 events gives a value for the asymmetry paraneter $\xi=0.95\pm0.06$. The energy dependence of the asymmetry is in satisfactory agreement with 2 component theory. A preliminary analysis of the momentum spectrum gives for the Michel parameter $\rho=0.79\pm0.03$. This error is compounded of 0.02 statistical error and a preliminary systematic error of 0.02. The number of events in each experiment will be approximately doubled.

**H5. Asymmetry Parameter in the Decay of $\mu$ Mesons.*** M. BARDON, D. BERLEY, AND L. M. LEDERMAN, *Columbia University.*—An experiment is in progress to measure the asymmetry parameter in the decay of $\mu$ mesons. Transversely polarized muons emitted near the cutoff angle in the decay in flight of 60-Mev positive pions are stopped in a Bromoform target, and are then precessed $\pm90°$ by a 1 $\mu$sec duration pulsed magnetic field. Electrons from the muon decay are then counted in two sets of counters placed on each side of the target. In contrast to earlier experiments,[1] the use of muons from decays in flight near the cutoff angle results in an accurate knowledge of their polarization; and hence in a much smaller uncertainty in the electron asymmetry parameter than heretofore obtained. The results are corrected for the polarization of the $\mu$ mesons; for the solid angle subtended by the counters, and for the extent of the region of the stopping mesons; and for the energy distribution of the observed electrons defined by the target and the detectors, as obtained from a Monte Carlo calculation. The results are shown to be rather insensitive to this last correction. The over-all systematic uncertainty is less than 3%. The result obtained for the asymmetry parameter is $\xi=0.97\pm0.05$ where the uncertainty includes statistics and systematics.

* This research is supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] D. H. Wilkinson, Nuovo cimento 6, 516 (1957).

**H6. Search for Low-Frequency Zeeman Transitions in Muonium.*** D. MCCOLM AND V. W. HUGHES,† *Yale University* AND A. LURIO, *IBM Watson Laboratory.*—Several experiments on the depolarization of muons in gases have suggested the possibility that muonium ($\mu^+-e^-$ bound state) is formed when positive muons are stopped in nitrous oxide gas.[1] An experiment is in progress to observe a low-frequency Zeeman transition in muonium and hence to provide a more specific test of muonium formation. A maximum change in events counting rate of 40% between the rf-on and rf-off conditions is predicted. One run has been made and no effect due to the rf was observed either in $N_2O$ (~3% statistics) or in A (~5% statistics). Since muonium will act chemicaliy much like a hydrogen atom, there is considerable question as to whether it will remain free in the gas during its lifetime since it will make many collisions with gas molecules. In particular an $O_2$ impurity could result in the formation of muonium oxide ($a^2\pi$ ground state) and an NO impurity could lead to a change in the hfs state due to an exchange collision.

* This research has been supported in part by the Air Force Office of Scientific Research, the Office of Naval Research, and the U. S. Atomic Energy Commission.
† Presently on leave at Columbia University.
[1] Hughes, Lurio, Malone, Lederman and Weinrich, Bull. Am. Phys. Soc. Ser. II, 3, 51 (1958); McColm, Hughes, Malone, Lederman and Lurio, Bull. Am. Phys. Soc. Ser. II, 3, 229 (1958).

**H7. Asymmetry Parameter in $\mu$-$e$ Decay.*** GERALD LYNCH AND J. OREAR, *Cornell University* AND S. ROSENDORFF, *Columbia University.*—A measurement of the asymmetry parameter in $\mu$-$e$ decay is in progress at Cornell and Cloumbia Universities. The muons under study came from $\pi^+$ mesons which were produced at the Nevis cyclotron. These pions decayed at rest in 600-micron thick G-5 nuclear emulsions on which was imposed a magnetic field of 25 000 gauss, the field direction being in the plane of the pellicles. It is assumed that the positron from the muon decay has an angular distribution of the form $1+\alpha\cos\theta$ where $\theta$ is the angle between the initial muon direction and the initial positron direction. The plates are area scanned for muon endings. Only those events for which the projected direction of both the muon and positron are within 45° of the magnetic field direction are recorded. From these the asymmetry parameter is estimated by the expression $2(S\text{-}O/S\text{-}O)$, where $S$ and $O$ are the number of recorded events in which the muon and positron directions are in the same and opposite quadrants, respectively. More than 35 000 $\mu$-$e$ decays have been looked at and the estimate of the asymmetry parameter obtained from these is $-0.295\pm0.021$

* This work was supported in part by the joint program of the Office of Naval Research and the Atomic Energy Commission.

**H8. Weak Interaction Experiments at the Berkeley Synchrocyclotron.*** ROY P. HADDOCK, *University of California, Berkeley.*—Two experiments have been completed since the Berkeley cyclotron meson beams became available in October, 1957. One experiment determined the helicity of the electron and positron[1] from $\mu$-decay. Experimentally some of the systematic errors will be eliminated by measuring both polarizations and theoretically a reversal of polarization clearly demonstrates the failure of the invariance of the $\mu$-decay under charge conjugation. The results indicate that $\beta^+$ is right-handed and $\beta^-$ is left-handed. For the two-component theory, $\mu^+$ is left-handed, and $\mu^-$ is right-handed. These results agree with the assumptions of (a) the two-component theory with lef-handed neutrinos, (b) conservation of leptons, (c) universal $\beta$-decay theory with $V$ and $A$ interactions, (d) complete polarization of both $\beta^+$ and $\beta^-$. The other experiment measured the $\mu^+$ beam polarization and the energy dependence of the asymmetry of positrons stopped in Li, C, and $ChBr_3$ using a magnetic spectrometer.[2] Using a Helmholtz coil to produce a depolarizing field in the $\mu$-stopper provided an unpolarized $\mu$-decay spectrum with the same $\mu$-beam and geometry as the polarized $\mu$-decay spectrum. The results agree with the two-component theory for a value of $R|\xi|=0.89$ where $\xi$ is the usual polarization parameter and $R$ is a measure

of the degree of depolarization in the stopping material and of the beam polarization.

* This work was done under the auspices of the U. S. Atomic Energy Commission.
[1] Macq. Crowe, and Haddock, UCRL-8263.
[2] Hans Kruger and Kenneth M. Crowe, UCRL-8370.

**J2. Asymmetry in the Decay of Σ Hyperons.*** RODNEY L. COOL,† BRUCE CORK, JAMES W. CRONIN,‡ AND WILLIAM A. WENZEL, *University of California, Berkeley.*—A search has been made for an asymmetry in the decay if $\Sigma^{\pm}$ hyperons. The $\Sigma^{\pm}$ were produced in the reactions $\pi^{\pm}+p\rightarrow\Sigma^{-,+}+K^{+}$. Detection and identification of the $K^{+}$ by a counter technique selects the above reactions and establishes the plane of production. Additional counters, which detect the pions from the Σ decay in coincidence with the $K^{+}$, measure the asymmetry with respect to the plane of production. The results yield the parameter $\alpha\bar{p}$, where $\alpha$ measures the strength of parity non-conservation and $\bar{p}$ is the average polarization of the Σ hyperon. The data give the following preliminary results: For $\Sigma^{-}$ produced by 1.0 Bev $\pi^{-}$, $\alpha^{-}\bar{p}=+0.02\pm0.05$; for $\Sigma^{-}$ from 1.1 Bev $\pi^{-}$, $\alpha^{-}\bar{p}=-0.06\pm0.05$; for $\Sigma^{+}$ from 1.0 Bev $\pi^{+}$, the decay mode $\Sigma^{+}\rightarrow\pi^{+}+n$ gives $\alpha^{+}\bar{p}=+0.02\pm0.07$ and the mode $\Sigma^{+}\rightarrow\pi^{0}+p$ gives $\alpha^{0}\bar{p}=+0.70\pm0.30$. The value of $\alpha^{0}\bar{p}$ for $\Sigma^{+}\rightarrow\pi^{0}+p$ strongly indicates that parity is not conserved. For the $\Sigma^{+}$ $\bar{p}\geq0.70\pm0.30$; thus we can conclude $|\alpha^{+}|\leq0.03\pm0.11$. The results therefore indicate that the asymmetry parameter $\alpha$ depends upon the isotopic spin states in the final pion-nucleon system. The dependence on the isotopic spin is compatible with the $|\Delta I|=\frac{1}{2}$ rule.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† On leave of absence from Brookhaven National Laboratory.
‡ Now at Palmer Physical Laboratory, Princeton University, Princeton, New Jersey.

**J3. Phenomenological Analysis of Hyperon Decay Rates and Asymmetries.*** S. A. BLUDMAN, *University of California, Berkeley.*—The $\Delta I=\frac{1}{2}\mu$ rule is incorporated into a previously discussed universal weak Yukawa interaction by assuming the simplest relation between chirality and charge operators. Expressing the $\Delta I=\frac{1}{2}$ rule by forming $\eta$ and $\Xi$ into isovectors $\mathbf{B}=(P,iP,-N)$ and $(\Xi^{-},i\Xi^{-},-\Xi^{0})$ and isoscalars $B_S=N$ and $\Xi^{0}$, we assume $\mathbf{B}$ occurs with $G\gamma_{\mu}(1+r\gamma_5)$, as in $\beta$ decay, and $B_S$ (which has no $\beta$ decay counterpart) with $G\gamma_{\mu}(1-r\gamma_5)$. Here $G$ is the constant previously fitted to the $\pi$ and $K_{\mu2}$ decay rates, and $r$ is the ratio of Gamow-Teller and Fermi coupling constants. Depending on the sign taken between the $\mathbf{B}$ and $B_S$ interaction terms, Σ decays into $N\pi^{+}$ in pure $S$ and into $N\pi^{-}$ in pure $P$ channels, or v.f. In either case, $\Sigma^{+}\rightarrow P\pi^{0}$ involves maximal $S$-$P$ interference and $\alpha^{0}=0.98$. Decay into $I=\frac{1}{2}$ proceeds via $\sqrt{2}G\gamma_{\mu}(\frac{1}{3}+\frac{2}{3}r\gamma_5)$ or $\sqrt{2}G\gamma_{\mu}(\frac{2}{3}+\frac{1}{3}r\gamma_5)$ depending on whether $\Sigma^{-}$ decay is pure $S$ or pure $P$. The second case, but not the first, leads to a $\Lambda^{0}$ decay rate in agreement with experiment. In this case, $\alpha_{\Lambda}=0.54$, and in Ξ decay, the decay rate is $1.6\times10^{10}$ sec$^{-1}$ and $\alpha_{\Xi}=0.64$

* Supplementary paper.

**K2. The Weak Four-Fermion Interaction.** R. E. MARSHAK AND S. OKUBO, *University of Rochester* AND E. C. G. SUDARSHAN, *Harvard University and University of Rochester.*—In September, 1957, we pointed out that four crucial experiments have to be redone (with different results!) if our theory were to survive. By October, 1958 this "decree" has been executed in full. The principle of chirality invariance has its origin in the elementary observation that the kinematic description of a Dirac field is independent of the mass and leads to a covariant, local decomposition of two chiral spinors. The two cases where (we think) we know the interaction Lagrangian; namely, for electromagnetic and weak interactions, the interaction is chiral invariant. The finite value for the mass, which leads to a coupling of the two chiral spinors does not affect the *kinematics* and hence, the symmetry imposed on the *structure* of the coupling term. In this sense both zero mass and finite mass fields are treated on an equal footing. The extension of the theory via the Gell-Mann tetrahedron with the $\Delta p$ pair for the fourth vertex leads to a strangeness violating Hamiltonian formed by the coupling of an isospinor current to an isovector current. The comparison of the theory with experiment and its contrast with the "old" $\Delta I=\frac{1}{2}$ rule as well as the relation between renormalized and bare coupling constants will be discussed.

**K3. Decay of Cascade Particles.** W. B. TEUTSCH, *Tufts University,* S. OKUBO, *University of Rochester* AND E. C. G. SUDARSHAN, *Harvard University.*—The decay chain $\Xi^{-}\rightarrow\Lambda+\Pi^{-},\Lambda\rightarrow P+\Pi^{-}$ is studied for arbitrary spin of the cascade particle. Since the Λ is believed to have spin $\frac{1}{2}$, two complex amplitudes fully describe the decay of $\Xi^{-}$. Several correlations of the form $(1+a\cos\theta)$ could be measured and a suitable list consists of the correlation of the proton momentum with the directions of $\hat{p}_{\Lambda},\hat{m}\times\hat{p}_{\Lambda}$ and $\hat{p}_{\Lambda}\times(\hat{m}\times\hat{p})$. The relation of these correlation parameters to the magnitude of the spin of the cascade particle as well as to the theory of weak interactions is discussed.

**K4. Universal Weak Boson and Fermion Interaction.*** MASAO SUGAWARA, *Purdue University.*—A modified interpretation of an ideal of divergenceless current due to Feynman and Gell-Mann[1] is investigated in detail in which some pairs of Bosons (pions and $K$ mesons) are assumed to exist, besides Fermion pairs, among members exerting a universal weak interaction. Especially we propose a pair of neutral $K$ meson and a charged pion, besides a pion-pair and pairs of leptons, nucleons and some hyperons. A strong evidence for this pion-$K$-meson-pair is its surprising fit to short-lived decay of neutral $K$-mesons. An essential presumption is here that pion-muon-decay is consistent with the present scheme though pion-electron-decay is left untouched. If we further presume a global symmetry of pion coupling to hyperons and $K$-meson interaction is simply assumed as comparatively weaker,[2] our present scheme seems consistent with all known data on decays of strange particles as far as reliable estimation could have been done. A complete scheme of a universal weak interaction is not obtained uniquely, since we have no particular necessity nor objection to some pairs of particles, from available theoretical and experimental information.

* Work supported by the Air Force Office of Scientific Research.
[1] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958).
[2] M. Gell-Mann, Phys. Rev. **106**, 1296 (1957).

**K5. A Universal Weak Boson-Fermion Interaction.** T. A. WELTON, *Oak Ridge National Laboratory.*—The *V-A* universal interaction between pairs of fermions, with due allowance for renormalization of the axial vector coupling constant, presently shows great promise. One drawback has been, however, the apparently false ratio predicted between the $\mu$ and $e$ decay modes of the charged pion, the usual calculation of the absolute rate of the $\mu$-mode yielding a divergent answer. It can be shown that no reliable cutoff procedure for obtaining a finite answer exists. A new and apparently consistent prescription has been given for closed loop calculations and has been here applied to obtain a plausible value for the decay rate. This value is too low by a factor of $10^{4}$ to explain the observed rate, and a direct $\pi$-$\mu$-$\nu$ interaction (of rather obvious form) has therefore been postulated to account for the known lifetime. With the dimensionless coupling constant adjusted in this way and the $K$ field replacing the $\pi$ field, the decay rate for $K^{+}\rightarrow\mu^{+}+\nu$ is correctly given to within 20%. Assumption of an identical interaction involving electrons rather than muons is apparently allowed by the most recent data on the electron suppression in the pion decay, and such

universality seems to be required by some of the $K$-decay branching ratios. It seems attractive to extend the universality so that only charge and baryon number are conserved, thus accounting directly for the hyperon decays to within an uncertainty factor of order unity.

**K6. A Model of Strong and Weak Couplings.** R. P. FEYNMAN, *California Institute of Technology.*—The consequences of a particular system of couplings are discussed. For the strong couplings the pion is assumed to be coupled to the isotopic spin vector of the baryons, and to be entirely responsible for the energy separation of $\Lambda$ and $\Sigma^0$. The kaons are coupled so that this degeneracy would not be lifted. The pion coupling is assumed to be relatively weak. The predictions are not in very satisfactory agreement with experiment, but the theory cannot be entirely excluded for resonances involving virtual pions may be involved. For the weak coupling written in the form $J_\mu^* J_\mu$, we take $J_\mu = \gamma_\mu a(e+\mu) + (\bar{P}+\bar{\Sigma}^+)\gamma_\mu a(N+Y) + (\Xi^0+\bar{Z})\gamma_\mu a(\Xi^-+\Sigma^-)$, where $a = (\frac{1}{2})(1+i\gamma_5)$, $Y = 2^{-\frac{1}{2}}(\Lambda-\Sigma^0)$ and $Z = 2^{-\frac{1}{2}}(\Lambda+\Sigma_0)$. With this the fact that $K^+ \to \pi^+ + \pi^0$ is slower than $K_1^0 \to \pi^+ + \pi^-$ is understood, as well as the fact that leptic decays of the $K^+$ and $K_2^0$ are much slower than a universal coupling would predict. But we do expect $K_1^0 \to \pi^\pm + e^\mp + \nu$ in a few percent of the cases, $\Sigma^+ \to N + e^+ + \nu$ with branching ratio 2.4%, and $\Lambda \to N + e^- + \bar{\nu}$ in ratio 0.8%, while the leptic decay of $\Sigma^-$ should be much less frequent. A number of inequalities expected for hyperon and kaon decays are not inconsistent with experiment.

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## Errata in 1958 APS Membership List

| | |
|---|---|
| *Hollomon, J. H. | Add asterisk denoting Fellowship |
| *Hunt, Franklin L. | Add asterisk denoting Fellowship |
| *Morrish, A. H. | Add asterisk denoting Fellowship |
| *Patterson, A. L. | Add asterisk denoting Fellowship |
| *Salisbury, W. W. | Add asterisk denoting Fellowship |
| *Rohrlich, Fritz | Department of Physics<br>The Johns Hopkins University<br>Baltimore 18, Maryland |
| *Wolcott, E. R. | Wolcott Research Corporation<br>917 Crenshaw Boulevard |
| *Spooner, Thomas | 1504 Poinsettia Drive<br>Fort Lauderdale, Florida |

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## MEETINGS AND DEADLINES FOR THE SEASON 1958–1959

| *Place* | *Meeting dates* | *Deadline date* |
|---|---|---|
| Los Angeles* | December 29–31 | past |
| New York | January 28–31, 1959 | November 14 |
| Austin, Texas | March 6–7 | January 9 |
| Cambridge, Massachusetts | March 30, 31, April 1 | January 16 |
| Washington, D. C. | April 30, May 1–2 | February 20 |
| Milwaukee, Wisconsin | June 18–20 | April 17 |
| Hawaii* | August 27–29 | June 17 |

* Abstracts for the Los Angeles and Hawaii meetings are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline day often fair to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west. Abstracts postmarked (at the point of dispatch) on deadline day are instantly rejected, and telegrams heralding their arrival are fruitless except in revenue to the telegraph company. Special delivery is usually useless and sometimes worse than useless. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

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## RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; *one must be an original*, the other may be an original or a carbon copy. *Carbon copies will not be accepted in lieu of originals:* they smear. *Abstracts must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. *Each abstract must be confined to a single page:* if it is too long for a single page it is too long to be printed. If we receive an abstract typed on two pages, we print only its first page. *Write each abstract as a single paragraph:* the suppression of paragraphs costs time and labor to the editors. *Do not use very thin paper;* a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. The American Institute of Physics will bless you if you type first the title of your abstract in lower-case with capitalized initials, then your name in capitals, then the name of your institution in lower-case underlined. It is strange how few people do this simple and obvious thing! Issues of the *Bulletin* are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It has now become an expensive business to make any change in an abstract, even the smallest, after the abstract has gone to press. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

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